

AERIAL ULTRA-LOW VOLUME SPRAYING FOR CONTROL OF  
NYMPHS OF THE AUSTRALIAN PLAGUE LOCUST  
*Chortoicetes terminifera* WALKER

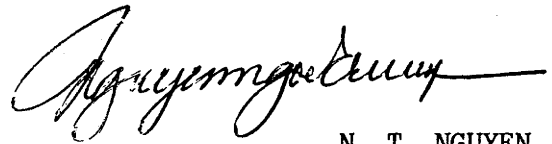
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A thesis submitted in fulfilment of the  
requirements for the degree of Master of Science  
of The Australian National University

Department of Forestry  
Faculty of Science  
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Statement of originality

Except where specific acknowledgments are given, the research work reported in this thesis is that of the author.

A handwritten signature in black ink, appearing to read 'Nguyen T. Nguyen', with a long horizontal flourish extending to the right.

N. T. NGUYEN



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## ABSTRACT

This thesis describes a study into certain aspects of the aerial ULV (ultra-low volume) spraying of nymphs of the Australian plague locust, *Chortoicetes terminifera* (Walker), by light aircraft equipped with Micronair AU.3000 rotary atomisers. The objective was to establish an effective and reliable method of control of the nymphs by aerial application of technical fenitrothion 128% w/v at the standard area dosage of 300 mL/ha.

The acquisition of aurally sprayed insecticide by the nymphs was investigated. Fenitrothion content in locust nymphs, collected at intervals from pasture which had been sprayed, was measured by gas chromatography. In sparse pasture, acquisition was mainly by direct impaction of spray droplets. Acquisition from residues also took place and was the dominant mode of dosing in denser pasture. The nymphs accumulated residual insecticide from contact and from feeding on the contaminated grass rather than from contact with deposits on the soil. Residual acquisition was most noticeable during the first hour or so after treatment, occurring at a rate which was approximately proportional to the total amount of insecticide recovered on grass per unit ground area.

The amounts of insecticide collected by the locusts were found to be dependent on factors other than, and in addition to, the applied area dosage. Generally, results suggested that in cases where residual acquisition was predominant, the nymphs could acquire more than the lethal dose - estimated at  $LD_{50}$  8  $\mu\text{g/g}$  - if treated at the

300 mL/ha dosage. Lower doses were measured when the nymphs acquired insecticide mainly by direct droplet impaction.

These findings suggested that one should aim to maximise the amount of insecticide deposited on the grass, and that nymphs infesting denser pasture could be treated more efficiently than those sprayed in bare, open ground.

The influence of wind speed, Micronair droplet size setting, aircraft flying height and track spacing on the deposition of spray droplets on grass, was also investigated. Average spray deposits which resulted from treatments in "strong" ( $>3$  m/s) winds were about six times higher than those for treatments in light ( $<1$  m/s) winds. Treatments using the  $50^\circ$  Micronair blade setting, which produced a relatively coarse droplet size, gave about three times more insecticide deposition on grass than treatments using the fine  $25^\circ$  setting. Aircraft flying height had little effect on average spray deposition, although higher altitudes tended to give more even spray distribution patterns. A wide 100 m track spacing gave satisfactory overlapping of spray swaths, and acceptably even spray distribution, when applied from a Cessna 185 aircraft.

Based on the above results, it was recommended that aerial spraying of nymphs of *C. terminifera* be conducted in winds stronger than about 3 m/s, using the  $50^\circ$  Micronair blade setting, aircraft spraying height of about 10 m and spray track spacing of 100 m. This recommendation was further tested in trials against infestations of nymphs of *C. terminifera*. Monitoring of the mortalities of the sprayed nymphs confirmed the biological

effectiveness of the proposed method. It was subsequently adopted for use in large scale aerial spraying campaigns, and was shown to give reliable and successful control of infestations of nymphs as well as settled swarms of adult locusts.

## ACKNOWLEDGMENTS

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## 1. INTRODUCTION

### 1.1. The Australian plague locust and its control

The Australian plague locust *Chortoicetes terminifera* (Orthoptera: Acrididae) (Figure 1) is indigenous to Australia, and has been recognised as a major agricultural pest from as early as 1870 (Casimir 1965). *C. terminifera* can infest much of the interior of south-eastern Australia. Most locust outbreaks are believed to originate in the normally arid Channel Country of south-west Queensland and adjacent areas in neighbouring States. There, scattered populations of locust can survive even under the most adverse conditions (Clark *et. al.* 1969, Clark 1972). When rain occurs, successful breeding results and locust numbers can increase significantly (Clark 1965). Depending on the timing and amount of rainfall (Hunter 1982), the locust can also accumulate fat reserve for long distance migration (Symmons and McCulloch 1980, Hunter *et. al.* 1981).

Migration usually occurs in a southerly direction towards the agriculturally more productive areas of New South Wales (NSW), South Australia (SA) and Victoria. The initial emigration from the interior can be followed by further successful breeding and emigration. The outbreak can thus develop into a major plague.

Unless the population growth is checked, either naturally or by control measures, the effects on agricultural production can be



Figure 1 - Adult Australian plague locust, *Chortoicetes terminifera* (Walker). Photograph shows a female locust (at about twice actual size) with the characteristic features of forewings with mottled markings, clear hindwings but for black tips, and red shanks on hind legs.

devastating. Pasture is mostly at risk initially, but successive waves of emigration can lead to the invasion of valuable cropping lands where the locust can inflict far more serious damage (Bullen 1975). Damages attributed to the locust plagues of 1933-1934 and of 1953-1955 have been conservatively estimated at hundreds of millions of dollars; the cost of lesser outbreaks can also be quite substantial (Symmons 1978).

In the event of a locust outbreak, insecticide spraying is the most if not only effective means of control. Biological control has been ineffectual since the control agents often cannot multiply quickly enough to check the growth in locust numbers. Spraying may be directed against either swarming adult populations or banding hoppers (nymphs) or both during locust control campaigns.

Campaigns to control locust infestations within each State are usually coordinated and supervised by the Department of Agriculture in that State. Infestations that pose an interstate threat are controlled by the Australian Plague Locust Commission (APLC). The Commission, which became operational in late 1976, is a locust monitoring and control organisation jointly financed by the Commonwealth Government of Australia and the State Governments of NSW, Victoria, SA and Queensland.

Swarming adult locusts (Figure 2) are highly mobile, and given the right conditions (Symmons and McCulloch 1980, Hunter *et. al.* 1981), can migrate hundreds of kilometres. Such large scale movement brings locusts to previously unaffected areas and can pose a





Figure 2 - Swarming adult plague locusts. A typical view through a swarm in flight.

significant logistic problem to the overall control effort. Spraying of infestations of locust nymphs (Figure 3) in the early stage of the outbreak can prevent the formation of swarms and lessen the risk of spreading of the outbreak.

Control of locust in the nymphal stage is usually carried out by landholders or by local pasture protection authorities, using ground spraying techniques. Most of these techniques are improvised using various spray equipment, not all designed for pesticide application (Wright 1980). Individual hopper bands (Figure 4) are sprayed where and when they are found by landholders. These treatments are generally successful in killing the locusts sprayed, but are not very effective in terms of overall population reduction since several bands in the infested areas can be easily missed by control teams (Wright 1980). They are also slow and labour intensive. Over-use of chemicals commonly occurs because spray equipment is often quite crude, and not properly calibrated, and because of the natural tendency of most people to apply liberal amounts of insecticides for a rapid kill.

Where the infestations are large, treatment of the whole infested areas is considered more effective. Broad-acre ground-misting vehicles are usually deployed by State Governments or local pasture protection authorities, to treat areas known to contain several hopper bands, complementing landholders' control efforts. These machines are still slow, however, and can only cover small areas. They are also restricted to areas which are accessible to road vehicles.

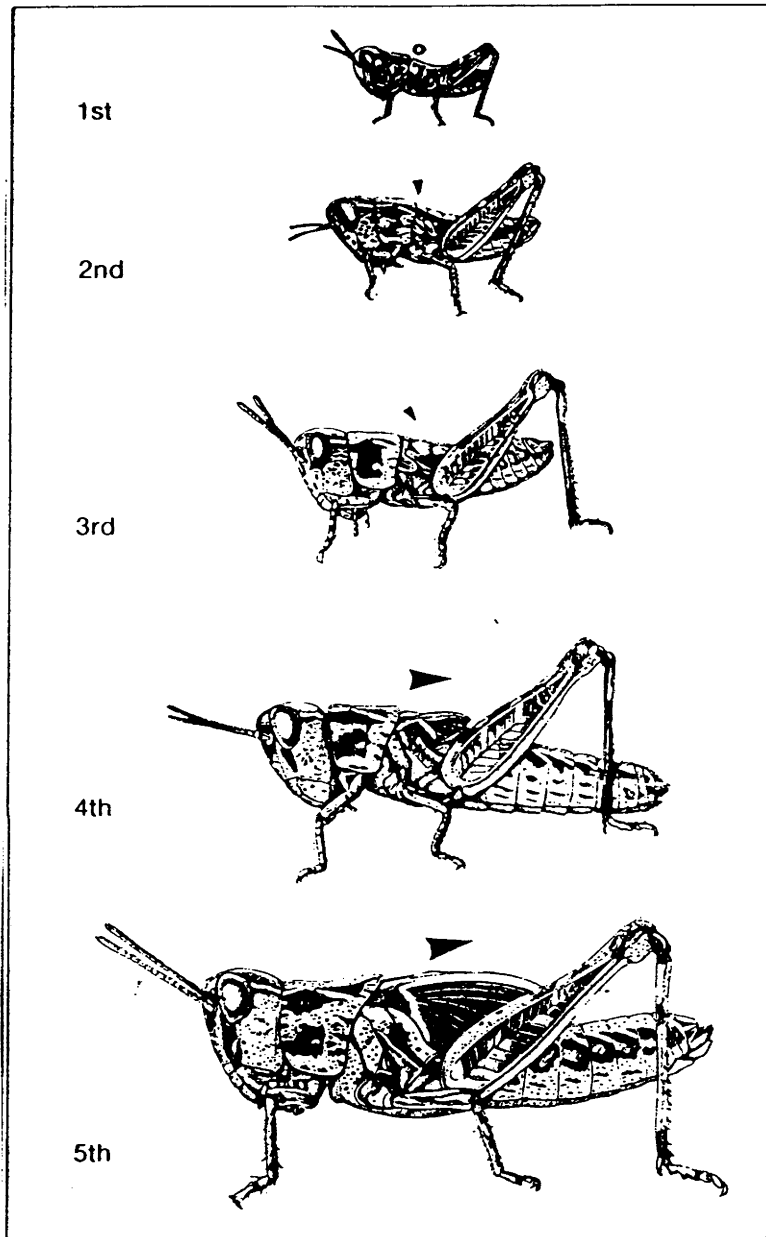


Figure 3 - Nymph of *Chortoicetes terminifera*. The five stages or instars of nymphal development prior to fledging (shown at about 3 times actual size); arrows indicate orientation of wing buds. First instar nymphs have no wing buds.





Figure 4 - Banding plague locust nymphs. Close-up view of part of a band of third to fifth instar nymphs.

Aerial spraying is far more effective and efficient as a method of treating large infestations. Much larger areas can be covered in less time and at lower costs with spray aircraft than with misting vehicles. In remote, inaccessible or sparsely populated areas, and against flying swarms of adult locusts, it is the only practicable method of control. The flexibility and speed with which aircraft can be deployed against infestations even in the remotest of areas, and the extent of area coverage afforded by them have made aerial spraying the major method of plague locust control. The APLC, because of its small staff and the large areas for which it is responsible for locust control, relies exclusively on aerial spraying.

#### 1.2. Developments in the aerial spraying of *C. terminifera*

Aircraft were first used in the control of *C. terminifera* in 1946 by the Victorian Department of Agriculture (Hogan 1949, 1952, 1955). These were mainly RAAF Dakotas or Beauforts which were fitted with rudimentary spraying equipment. Infested areas were simply "drenched" with large volumes of water-based sprays. The insecticides used were organo-chlorines such as BHC, DNC, chlordane, toxaphene. At the time, a limited number of studies were carried out into spray droplet distribution by Hogan (1951), as part of the development of spraying method.

Much of the work in developing aerial spraying of locusts in Australia was carried out subsequently in NSW (Casimir 1976). Since

locust control in NSW is normally conducted in remoter areas which lack the facilities to service large transport planes, such aircraft were not considered suitable. In addition, the shortage of water in these semi-arid areas required the development of alternative techniques to the high-volume water-based spraying used in Victoria.

In 1955, the NSW Department of Agriculture started to experiment with swarm spraying from light aircraft (Casimir 1958). Successes led to the regular use of Tiger Moth and Auster aircraft for the application of lindane in diesel oil to treat flying swarms of *C. terminifera*. These aircraft were subsequently replaced following the 1966-1967 "locust season", by specially designed agricultural aircraft such as the Cessna Agwagon and the Piper Pawnee. The newer aircraft offered considerable advantages in payload, speed and safety over the earlier light aeroplanes. The 1966-1967 season also marked two other significant developments. Successful field trials carried out during that locust season indicated that not only aerial application of undiluted technical grade insecticides at ultra-low volume (ULV) rates could be used for locust control, but that nymphal infestations could be treated successfully by this method (Casimir 1976).

ULV application refers to the spraying of either undiluted insecticides or of specially formulated products in low-volatility carrier oils, at very low area dosages, generally less than about 5 L/ha (Maas 1971). The use of such low volumes requires that the chemical be distributed in very small droplets, commonly less than 100  $\mu\text{m}$  <sup>in diameter</sup> for adequate spray coverage.

ULV application technique originated from work initiated in 1945 by Gunn *et. al.* (1948), in an effort to establish methods for the control of locust plagues in Africa. Pioneering multi-disciplinary studies were carried out (Kennedy *et. al.* 1948, MacCuaig 1958, 1962, Sawyer 1950, Wootten and Sawyer 1954, Weis-Fogh 1952, 1956), which led eventually to the first use of undiluted insecticides at ULV rates (Rainey and Sayer 1953, Rainey 1958). Because of its many advantages over conventional water-based spraying, ULV spraying has subsequently found increasing applications in diverse fields of agriculture, forestry and public health (Lofgren 1970, Joyce 1974).

ULV spraying by aircraft, has become an integral and increasingly important method of controlling locust in NSW since the early 1970s. Aerial spraying of locust nymphs in particular has considerably widened the scope of, and resulted in substantial savings in, the control of *C. terminifera*. The advantages of ULV spraying have been discussed by Casimir (1976).

With the advent of ULV spraying, the insecticide lindane was replaced firstly by technical malathion and then by technical fenitrothion, both of which are organo-phosphates. In the area of spray equipment, the replacement of the conventional boom and nozzles, adapted from that used in ground spraying, with the Micronair rotary cage atomiser represented a significant improvement. The latter is considered more suitable for the production of the small and uniform <sup>size of</sup> spray droplets required in ULV application (Sayer 1969, Matthews 1974, Spillman 1979).



### 1.3. Present study

#### 1.3.1. Objective

As discussed earlier, aerial ULV spraying has been employed regularly in campaigns against major infestations of plague locust nymphs, since the early 1970s. Technical fenitrothion 128% w/v has been recommended at the area dosage of 300 mL/ha; the insecticide is commonly applied in parallel spray runs across wind about 30 m apart (Casimir 1976). However, there has been no specific recommendation as to how this dosage should be best applied, with regard to such factors as wind speed and turbulence, spray equipment and aircraft speed, <sup>height</sup> and the interaction between spray deposits and the insect pests during and after the application, which are now known to influence treatment results as much the area dosage applied (Spillman 1979).

Lack of appreciation of the influence of such factors in the conduct of aerial spraying of *C. terminifera* nymphs, has meant that control can be unreliable. Consequently, because of the significant risks of control failure and dire consequences to agricultural production, field staff directing control operations have tended to apply higher dosages than the recommended rate to ensure success. This is undesirable, not only from an economic viewpoint, but also because of the side effects associated with the unnecessary and excessive use of chemicals such as environmental contamination and the development of insecticide resistance (Graham-Bryce 1978).

Work described in this thesis was initiated in 1977 to investigate how the delivery of small ULV insecticide droplets, from spray aircraft to *C. terminifera* nymphs on the ground, may be influenced by spraying parameters other than the applied dosage. The primary objective was to gain sufficient insight to enable the identification of circumstances under which control would be most effective. It was required to establish simple guidelines on a method of aerial control of *C. terminifera* nymphs, based on the use of light aircraft equipped with Micronair spray atomisers to apply technical fenitrothion 128% w/v at 300 mL/ha.

#### 1.3.2. The project

This practical requirement made it necessary to limit the scope of the study to areas which would be most likely to yield information enabling the specification of a suitable spraying method. Two topics selected for investigation were the collection of insecticide by the nymphs and the deposition of spray droplets onto identified target sites where they would be picked up by the locusts. Results of these investigations are reported in this thesis.

The main experimental techniques used in the study are described in Section 2. Section 3 reports the results of field trials aimed at understanding the ways in which locust nymphs acquired fenitrothion insecticide, following its aerial application as ULV concentrate. These studies led to the identification of the main target surfaces to which the insecticide should be delivered for maximum effectiveness.

Experiments investigating the effects of a number of factors on spray delivery to these targets are described in Section 4. These experiments were designed to determine conditions under which spray recovery on targets could be maximised. Results formed the basis for the formulation of a method for aerial spraying of the nymphs. The resultant spraying method was subsequently tested in trials against infestations of nymphs, the results of which are reported in Section 5.

## 2. GENERAL METHODS

### 2.1. Aircraft and spray equipment

Spray aircraft used in the study were the high-wing three-seater Cessna 185s (Figure 5), which are regularly used in locust control work. These general aviation aircraft were equipped with a "belly tank" and an electrical or air-driven pump for the chemical. Their main spray equipment consisted of four Micronair AU.3000 rotary atomisers (Figure 6), two under each wing (Figure 7); aircraft used in the trials described in Section 3 were equipped with two atomisers only.

The Micronair atomiser was first introduced in the 1950s (Britten and Norman 1956) for the aerial spraying of undiluted insecticides to control locusts in Africa. Much improvement has since been made to the atomiser, although the basic rotating cage design remained essentially unchanged. It has been the most widely used rotary atomiser in aerial spraying.

The Micronair AU.3000 model was the latest model at the time of the study. Its design was described in detail in the AU.3000 Handbook. Essentially, the atomiser consisted of a cylindrical wire-mesh gauze, 28 cm in diameter, rotating around a central spindle. The spindle was hollow and connected to the spray reservoir and pump, via an adjustable orifice at the front end of the atomiser. Chemical flow rate to the atomiser could be controlled by selecting



the appropriate orifice size and pump pressure. Insecticide was fed into the spindle and discharged out of it through a series of holes, designed for even liquid distribution, onto the gauze where droplets were formed by centrifugal force as the gauze rotates. Some atomisation also occurred due to the splashing of the liquid on impact on the gauze (Parkin 1980).

Five impeller blades driven by the airstream created by the forward movement of the aircraft, provided power to rotate the atomiser. These blades had variable pitch (blade angle) settings which could be selected to obtain different rotational speeds of the gauze for a given aircraft speed. There were six nominal settings marked between  $25^{\circ}$  and  $50^{\circ}$  in increments of  $5^{\circ}$  (Figure 8). The smaller the blade angle, the squarer were the blades set to the airstream, the faster the atomiser rotated to produce finer spray droplets. The size and range of droplets produced (spray droplet spectrum) could therefore be selected by setting the blades to the desired angle. However, the control of droplet size and range achieved was not exact, since factors such as chemical feed rate and wind shear occurring as the droplets were emitted into the fast moving airstream, could influence the final make-up of the spectrum (Parkin, personal communication).

The spray aircraft used was also equipped with a counter mounted on the cockpit dashboard to indicate the revolution speeds of the cages, enabling their continual monitoring during spraying by an on-board observer. The observer also monitored other information such as spray emission rate, and aircraft speed (about 190 km/h).



Figure 5 - Cessna 185 aircraft, equipped with Micronair spray gear. The aircraft is fitted with four Micronair AU.3000 rotary atomisers under its wings and an aerodynamic "belly" spray tank.



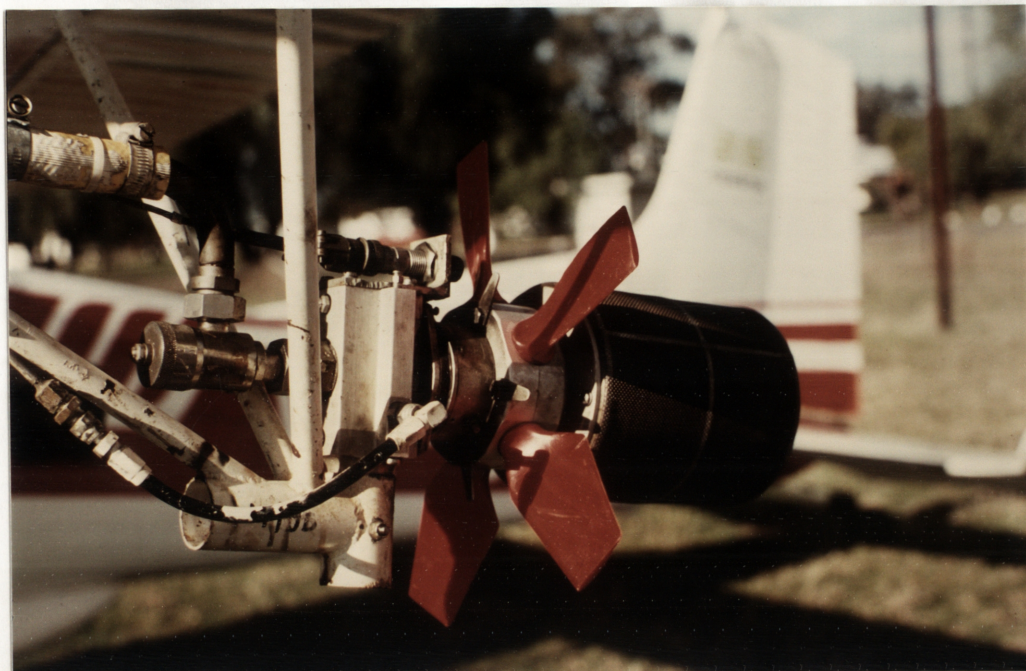


Figure 6 - Micronair AU.3000 rotary atomiser, as mounted on the Cessna 185 aircraft. The chemical supply line (with yellow markings) is shown above and to the front of the atomiser, feeding through the adjustable orifice unit. The magnetised revolution counter, mounted above the spindle, is activated by the small metal blades located immediately in front of the atomiser impellers. The impeller blades are shown set at the 25° angle. The hydraulic brake fluid line feeds through the small port to the left of the mounting block; this braking system allows the pilot to stop the atomisers from rotating, when desired.

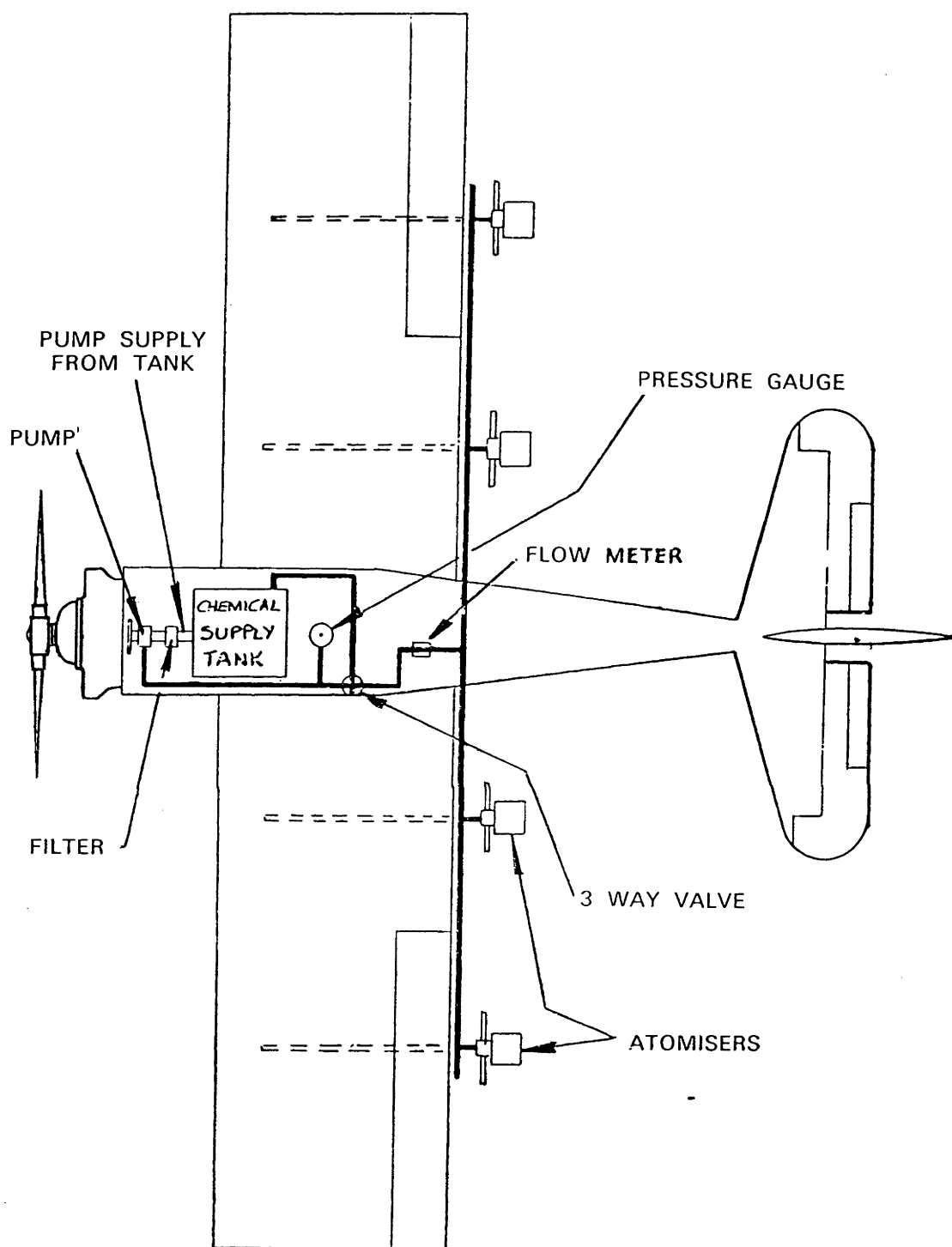


Figure 7 - Schematic layout of a Micronair installation.

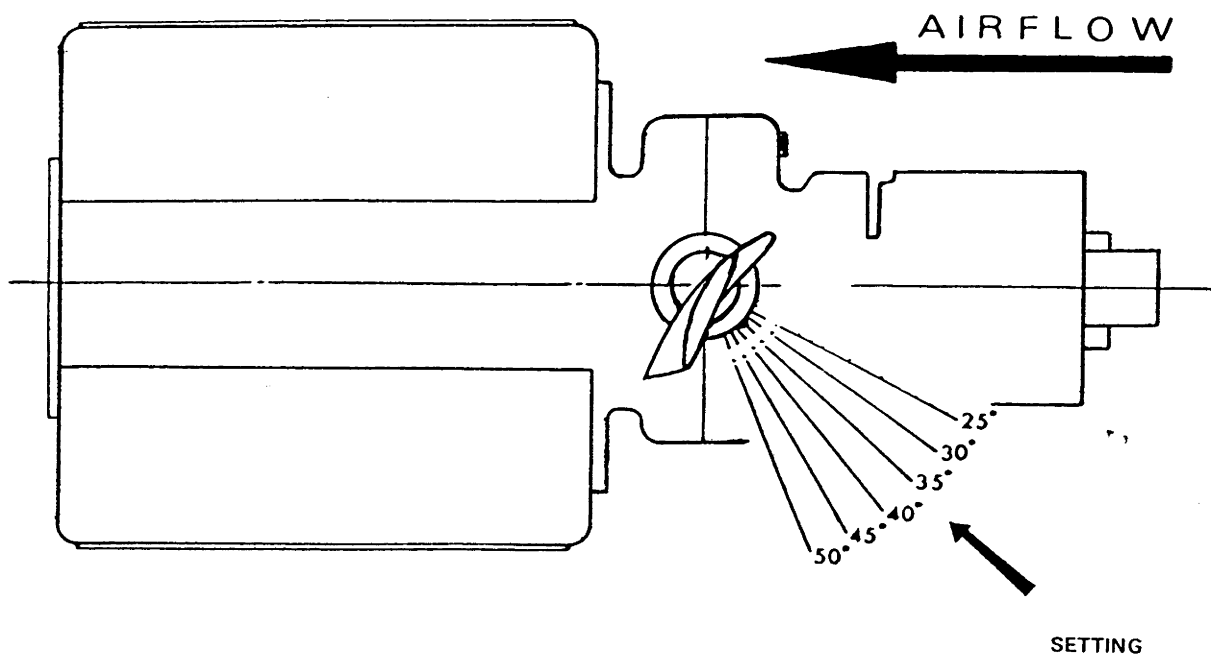


Figure 8 - Sketch of blade angle markings on a Micronair atomiser, showing the 35° setting being selected.

## 2.2. Measurement of spray deposits

### 2.2.1. Introduction

Methods of sampling and measurement of spray deposits can be classed into two broad categories :

- (a) Chemical analysis techniques which directly or indirectly measure the amount of insecticide, chemically extractable from the sprayed samples. Gas chromatography (GC) and high pressure liquid chromatography (HPLC) are examples of direct measurement methods. Indirect techniques such as colorimetry and fluorimetry (Sharp 1974) measure the amount of dye or fluorescent materials, which has been added to the insecticide at known concentrations, from which the amount of insecticide collected on the sprayed samples can be deduced.
- (b) Droplet sizing techniques which involve the counting and sizing of individual droplets in samples of deposits; deposit volumes can be calculated based on the number and sizes of the droplets. More information can thus be extracted on not only the amount of insecticide but also the make-up and distribution of deposited droplets. Such information can provide more insight into droplet behaviour than that provided by chemical analysis.

Traditionally, a variety of artificial surfaces have been employed to sample spray deposits. The commoner ones are Kromekote cards or coated glass slides, on which depositing droplets which may or may not be dyed will leave visible markings (Akesson and Yates 1974). Techniques relying on artificial surfaces are simple and convenient to handle, but have certain drawbacks. They provide only indirect representation of the actual deposit, which may or may not be accurate because the sampling surfaces used do not often closely simulate natural target surfaces of the sprays such as leaves (Himel and Moore 1967, Himel 1969, Himel and Uk 1975, Uk 1977). For more direct and accurate measurement of deposits, Himel and co-workers have developed techniques of adding dye or fluorescent materials to the sprays which allow the measurement of individual droplets on biological target surfaces.

Both chemical analysis and droplet sizing techniques were used, where appropriate in this study. They are described below:

#### 2.2.2. Gas chromatographic analyses

These analyses were carried out at the Australian Government Analytical Laboratories. They were used to determine the total amounts of insecticide, both deposited externally and absorbed internally, in sprayed locust nymphs and in sprayed grass. Samples collected for analysis were immediately chilled in a 12 volts d.c. portable freezer (at about  $-5^{\circ}\text{C}$ ) to prevent degradation of the



fenitrothion, then despatched to the laboratory. There they were weighed, finely chopped up and soaked overnight in re-distilled petroleum ether to extract the insecticide. Fenitrothion content of the samples was determined by gas chromatographic (GC) analysis of the extract, using a flame photometric detector.

### 2.2.3. Droplet sampling and sizing techniques

These techniques were employed to monitor in some details, the distribution of insecticide deposits on vegetation in an aerially sprayed area. Attempts to trace droplets directly on grass leaves were abandoned after a number of tracer materials tested were found unsuitable for use with fenitrothion, which is a viscous and essentially opaque liquid.

An artificial sampling technique was developed employing a thin and flexible paper sensitive to ULV sprays. This paper had an 80  $\mu\text{m}$  black backing coated with a 6.5  $\mu\text{m}$  layer of white "wax". The wax would dissolve on contact with fenitrothion, leaving permanent black circular stains on the paper (Figure 9). The sizes of the stains could be related to the airborne droplet sizes by a factor which was a function of droplet size. For fenitrothion droplets between 80  $\mu\text{m}$  and 120  $\mu\text{m}$  <sup>in diameter</sup> which was approximately the range of interest in this study since they contained most of the spray volume, calibration by the magnesium oxide slide method (May 1949) indicated that their stains were approximately 2.5 times larger than their airborne sizes.



To sample spray deposits on grass, small 3 x 25 mm strips of the paper were attached lengthwise on the grass leaves, with double sided adhesive tape (Figure 10). At the completion of treatment, the strips were removed and placed on microscope slides for storage and later analysis.

Sizing and counting of droplet stains were carried out on a Quantimet 720 Image Analysing Computer (Figures 11 and 12). The paper samples were presented to the epidiastope (Figure 12), to be fully scanned by a vidicon camera. The scanner output was transmitted to an image detector which was programmed to select features for measurement based on a pre-set threshold "grey" level. Features which were less grey than the threshold would be rejected and not be sized and counted. The images scanned were also displayed on a video display terminal (Figure 11), with those accepted for measurement marked by "flags". The displayed images could be edited by the operator as necessary, using a light pen. Images of irregular features such as scratch marks on the paper could thus be deleted (unflagged) and overlapping droplets separated, to eliminate errors due to the processing of unwanted features.

The threshold grey level was set to allow sizing of droplets as small as 20  $\mu$ m. Smaller droplets were not sized and counted, not only because of possible errors due to their low grey levels merging with the background, but also because they could not be easily distinguished from flaws on the paper surface. Their omission would

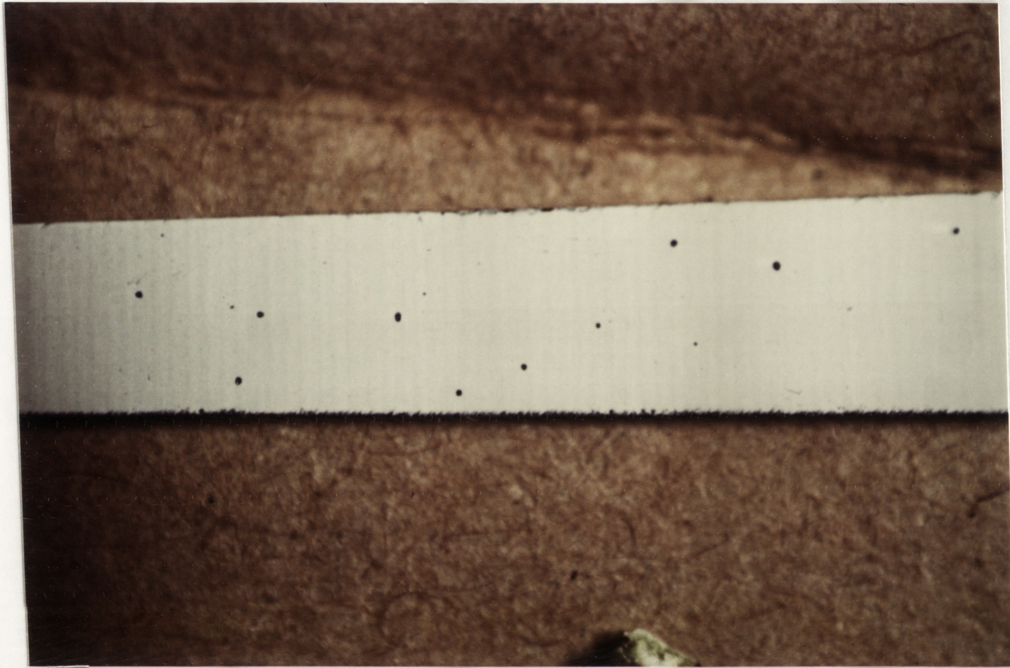


Figure 9 - Spray droplet stains on a strip of sampling paper, shown at about 10 times actual size.





Figure 10 - Deposit sampling with small sensitive papers, attached to grass leaves.



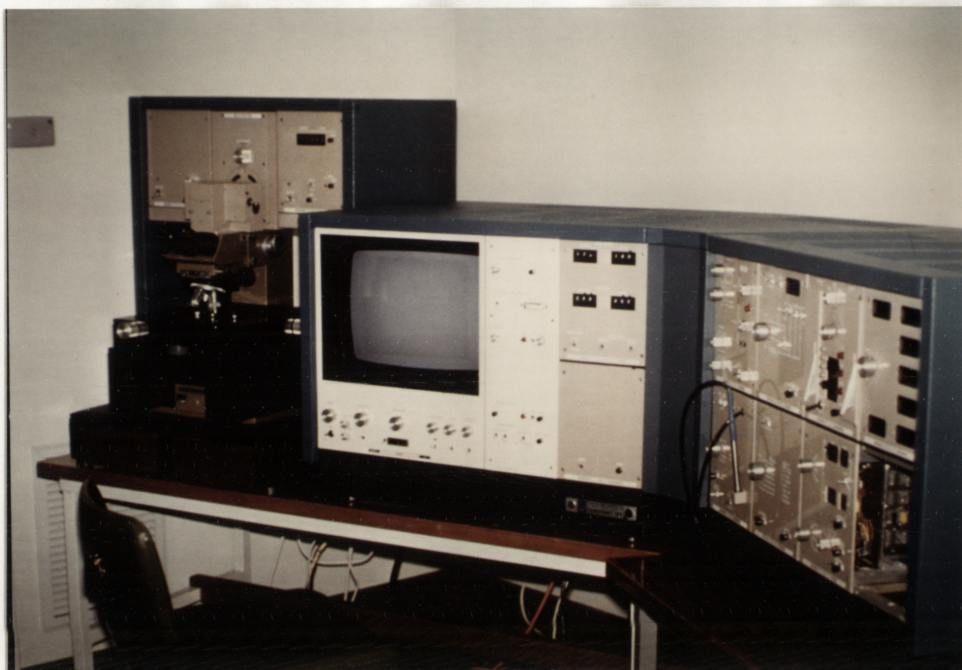


Figure 11 - Quantimet 720 Image Analysing Computer System - Central processors, video display unit and scanning microscope.





Figure 12 - Quantimet 720 Image Analysing Computer System - Scanning epidiascope. The epidiascope cover has been removed for this photograph which shows a microscope slide with paper samples ready to be scanned.

lead to an under-estimation of the number of droplets sampled but would not significantly affect the estimation of spray volumes deposited, due to the negligible volumes of these droplets.

The Quantimet was programmed to measure the diameters of the stains and sort them into eight size classes, then to transmit the data to an Andromeda Systems 11/B micro-computer for storage and further processing. The micro-computer carried out the conversion of stain sizes to droplet sizes, the calculation of various parameters such as droplet numbers, deposit volumes and densities, droplet size spectra, and some basic statistical analyses. In calculating droplet volumes, it was assumed that the number of droplets in each size class was uniformly distributed within that size range.

#### 2.2.4. Accuracy of droplet sampling and sizing

To determine if the techniques described, which relied on artificial sampling, could measure spray deposit on grass with acceptable accuracy, comparative tests were carried out using the tracer technique "reversibly soluble fluorescent pigments (RSFP)" (Uk 1977) as the standard. The study techniques were assessed for their capability to correctly measure deposit volumes, as well as other characteristics of the spray deposit such as droplet numbers, sizes, size distribution and droplet densities.

The tests involved spraying a small area ( $5 \text{ m}^2$ ) of grass with hand-held spinning disc Mini-ULVA sprayers, whose spinning speed could be varied by changing the d.c. voltage supply to change the

spray droplet sizes. Paper strips for droplet sampling had been attached to grass leaves in the area. The spray mixture consisted of 80% acetone and 20% 2-methylpentan-2,4 diol, and was traced with orange-yellow fluorescent pigments in melamine formaldehyde sulphonamide resin dissolved at about 20 g/L (Figure 13). Both the paper samples and the leaves to which they were attached were collected for comparative analysis. The paper samples were analysed on the Quantimet. The leaf samples were analysed using the digitising technique by Nguyen and Jarvis (1982). The ratios of stain size to droplet size for the spray mixture had been calibrated as 1.15 for the leaf and 1.23 for the paper surfaces.

There were no significant differences between the average volumes per unit area on the paper and those measured directly on the leaf by the RSFP technique ( $t$ -test,  $P > 0.1$ ); the average error was estimated at 6% to 10%. The v.m.d.'s (volume median diameter, droplets larger than which contain 50% of the total spray volume) measured by both techniques were similar over the range of droplet sizes tested (Figure 14). The paper samples however gave significantly fewer droplets in the range 20-40  $\mu\text{m}$  than counted on the leaves ( $t$ -test,  $P < 0.05$ ). This under-estimation of the number of small droplets led to the over-estimation of the n.m.d. (number median diameter, droplets larger than which make up 50% of all spray droplets), by up to 10  $\mu\text{m}$  (Figure 15). With coarser sprays whose n.m.d.'s were larger than about 50  $\mu\text{m}$ , the difference between droplet numbers counted was not significant ( $P > 0.1$ ).

It was concluded that the techniques of droplet sampling and

analysis used in the study would provide acceptably accurate representation of the amount of insecticide deposited on the grass surfaces. Results pertaining to droplet numbers should be interpreted with care, especially where droplets smaller than about 50  $\mu\text{m}$  could be present in large numbers.





Figure 13 - Fluorescence traced droplets on a leaf, under ultra-violet illumination (magnified 4 times).

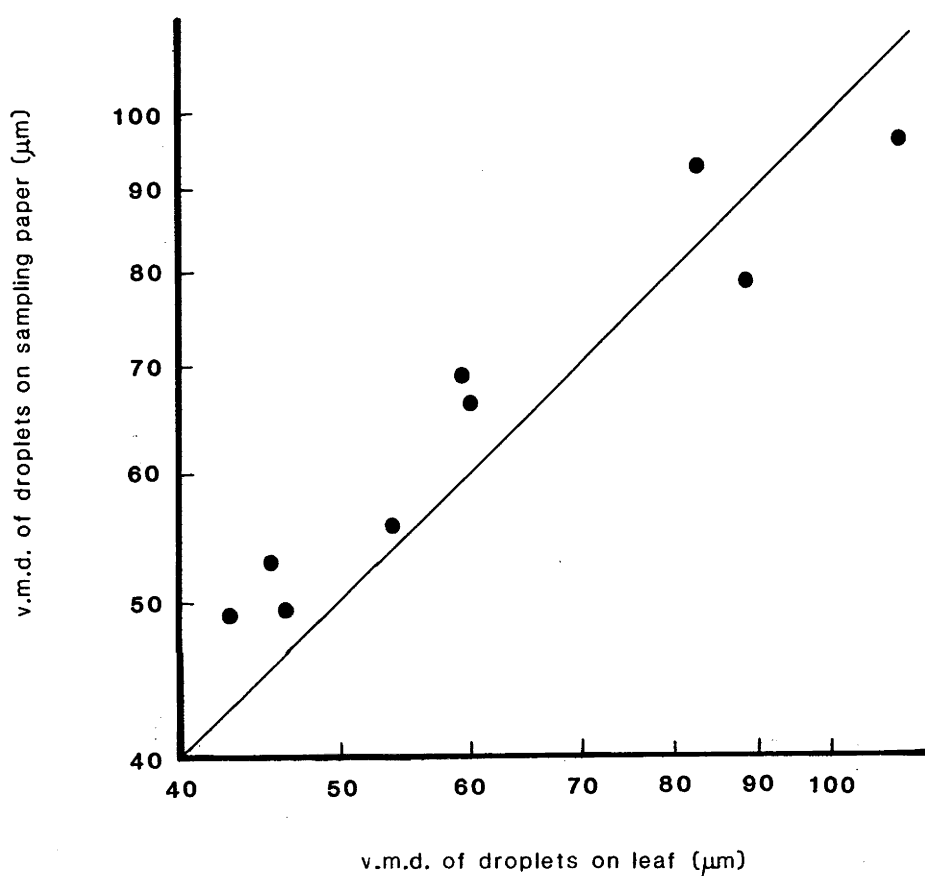


Figure 14 - Relationship between the volume median diameters of various spray droplet deposits as measured directly on target leaf surfaces using the reversibly soluble fluorescent pigments (RSFP) technique, and indirectly on sensitized paper strips attached to leaf surfaces.

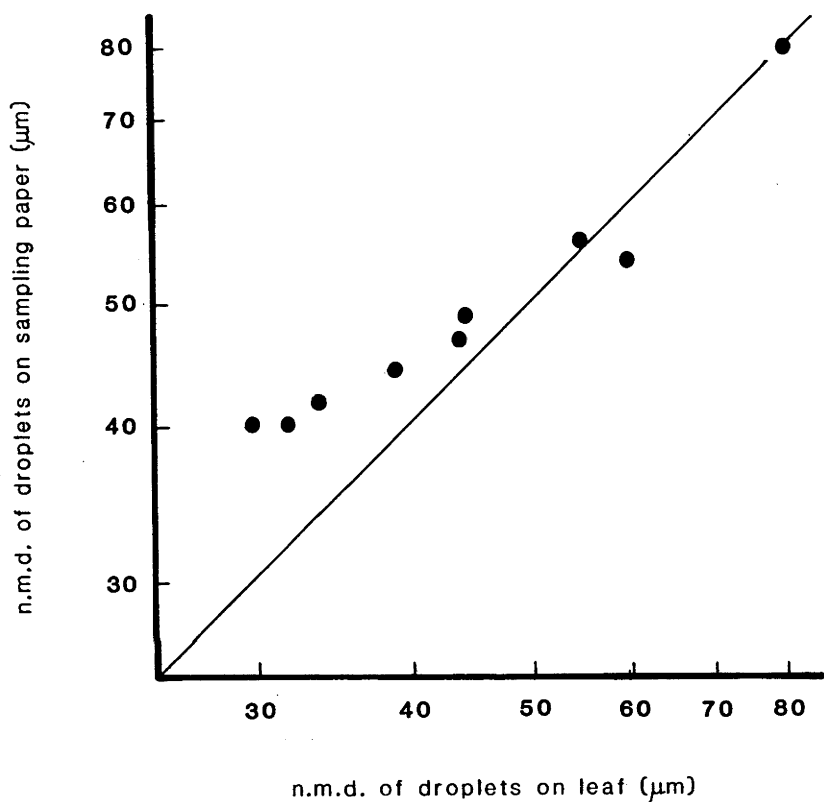


Figure 15 - Relationship between the number median diameters of various spray droplet deposits as measured directly on target leaf surfaces using the reversibly soluble fluorescent pigments (RSFP) technique, and indirectly on sensitized paper strips attached to leaf surfaces.

### 3. THE ACQUISITION OF INSECTICIDE BY NYMPHS OF *C. TERMINIFERA*

#### 3.1. Introduction

Nymphs which are sprayed from the air can acquire insecticide by direct impingement of insecticide droplets, by indirect means such as ingesting contaminated grass and coming into contact with spray deposits, or by a combination of both direct and indirect routes of entry.

Increased efficiency would result if a higher proportion of the spray could be directed to the entry route through which the locust nymphs would acquire insecticide more effectively. It was important therefore to know how the nymphs would acquire aerially sprayed insecticide, in order to define the appropriate biological target surfaces (Matthews 1977) on which spray droplets should be deposited. This aspect had previously not been studied in *C. terminifera* nymphs. Experiments in which higher mortalities were recorded amongst unsprayed nymphs caged with sprayed vegetation than amongst those collected from treated pasture (Nguyen 1979, 1980), suggested the importance of the indirect mode of acquisition. However, results of such caging tests were not conclusive because they could not faithfully reproduce conditions in the field.

The experiments described in this Section aimed to determine how nymphs of *C. terminifera* acquired aerially sprayed ULV fenitrothion. The response of the nymphs to doses acquired in the





Figure 16 - A Cessna 185 aircraft making a spray run. This aircraft is equipped with two Micronair atomisers.

field was also monitored to assess the biological significance of the different manners of spray acquisition.

### 3.2. Methods

#### 3.2.1. The trials

Grazing pastures near Longreach, Queensland, which were heavily infested with bands of third and fourth instar nymphs, were treated (Table 1). The aircraft applied insecticide in evenly spaced crosswind spray runs, from approximately 5 m height (Figure 16). The Micronair blades were set at the 50° pitch. The fenitrothion dosages applied were deliberately set lower than the recommended rate of 300 mL/ha (0.38 kg/ha) (Casimir 1976), to allow the collection of several samples of sprayed nymphs before a large proportion of the population was dead or moribund from the treatments.

In each trial, a band of locust nymphs near the centre of the block was selected for the monitoring of fenitrothion content in the treated hoppers. In trials 3.2 and 3.3 which were in fact one application, it was possible to monitor simultaneously two sections of one large hopper band which infested two adjoining areas of distinctly different vegetation characteristics (Table 1). This was also the case with trials 3.8 and 3.9.

The aircraft commenced spraying 600 m upwind of the selected hopper band, and ended well downwind. A stop watch was started the moment

TABLE 1 - DETAILS OF TRIALS USED FOR ASSESSMENT OF THE ACQUISITION OF FENITRO-  
THION INSECTICIDE BY NYMPHS OF *C. TERMINIFERA*.  $I_G$  IS THE 'GRASS COVER INDEX'

(SEE PAGE 38).

Trial no.	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
Date	7/11/79	9/11/79	9/11/79	15/2/80	15/2/80	16/2/80	16/2/80	17/2/80	17/2/80
Time	11:15	11:15	11:15	11:15	11:15	11:15	11:15	11:15	11:15
Emission rate (L/min)	4	4	4	4.7	3	3	3	3	3
Track spacing (m)	60	50	50	50	50	60	50	50	50
Area dosage (mL/ha)	200	240	240	290	180	150	180	180	180
Wind speed (m/s)	0-2	5-6	5-6	3-4	3-5	2-4	3-6	0-3	0-3
Temperature (degree C)	29	30	30	23	21	27	27	23	23
Average vegetation characteristics :									
% cover	50	5	80	45	20	30	60	20	40
height (cm)	20	7	50	10	15	10	10	20	30
$I_G$ index	10	0.4	40	4.5	3	3	6	4	12

the spray aircraft passed directly overhead of the band. At intervals (see Table 2) up to 3 hours thereafter, samples of nymphs (over 20 insects) were sweep-netted from the band; the nets were washed and dried before re-use to avoid cross contamination. These samples were later despatched for GC analysis of the amounts of fenitrothion collected.

The amounts of insecticide residues deposited on the vegetation near the band was also estimated by GC analysis. These were determined from five samples of grass (containing 5-10 g) collected from each trial block in the vicinity of the selected hopper band; only one sample was taken from trial 3.2 where the ground was virtually bare. The product of average height (m) of the grass and the percentage of ground area covered by the vegetation gave some measure of the amount of vegetation per unit ground area - the "grass cover index"  $I_g$  (Table 1). The product of  $I_g$  and the average residue level on grass (expressed as  $\mu\text{g/g}$ ) provided a crude measure of the amount of insecticide residues on grass per unit ground area - the "recovery index"  $I_R$ .

Results of GC analyses were not corrected for extraction efficiency, which was over 90%. It was likely that more insecticide could be extracted from samples in which a greater proportion of chemical had been absorbed through the cuticle rather than through gut tissue following ingestion.

### 3.2.2. Manner of insecticide acquisition



Any increases in the average insecticide content (or dose) with time in successive samples of nymphs after the overhead passage of the aircraft would indicate that residual acquisition had occurred in that trial. As a first approximation, it was assumed that the dose collected increased linearly with time of sampling. Estimates were then made of the rate and amount of insecticide which had been accumulated from residues, as well as the amount attributable to direct impingement of droplets. The direct dose was assumed to be the dose at "zero" time, or the moment that the aircraft passed overhead of the band. The actual direct dose would in fact be less than this, since the nymphs would have collected some insecticide from residual deposits, during the 8-10 minutes between spray commencement and overhead passage of the aircraft. The amount of insecticide<sup>1</sup> collected indirectly was assumed to be the difference between the total dose acquired and the estimated direct impaction dose. An estimate was also made of the dose that would have been collected by the nymphs had the area dosage been 300 mL/ha, by assuming that for precisely the same spraying conditions, the amounts acquired would have been proportionally higher.

Insecticide acquired indirectly could have been acquired from residues on the vegetation or from deposits on the soil or both. Trial 3.2, where the ground had virtually no grass cover, provided an opportunity to determine the amount of insecticide acquired by the nymphs from residual deposits on the soil only. Five ULV spray sensitive cards 75 x 50 mm (Type CF1, CIBA Geigy, Switzerland) were placed on the ground within the selected hopper band, to sample droplets settling on the ground. Deposits sampled were later

analysed on a Quantimet 720 Image Analysing Computer for the average volume deposit.

### 3.2.3. Response to fenitrothion doses

To estimate the response of the nymphs to doses acquired, some of the samples of sprayed nymphs were divided in half. One half was frozen for subsequent GC analysis, and the other kept caged with untreated grass to assess mortality after 48 hours. As an additional check, the bands from which these samples were collected, were tracked daily and their <sup>population</sup> densities 2 days after spraying were estimated and compared with densities before treatment. Band movement following treatment was usually small or, where significant, proportions of the hoppers were dead or dying, virtually nil.

## 3.3. Results

### 3.3.1. Manner of insecticide acquisition

The mean fenitrothion content in the sprayed nymphs at various times after the passage overhead of the aircraft are summarised in Table 2. Figure 17 presents examples of the variations of doses with time in three trials.

In trials 3.2, 3.5 and 3.6, there was no significant change with time ( $P > 0.1$ ) in the mean dose from that measured in hoppers sampled soon after the aircraft had passed overhead. This indicated that insecticide had been acquired primarily, if not solely, by direct

TABLE 2 - ACQUISITION OF FENITROTHION INSECTICIDE BY NYMPHS OF *C. terminifera*  
FOLLOWING AERIAL APPLICATION AT RATES BETWEEN 200 and 290 ML/HA.

Sampling time (minutes)	3.1	3.2	3.3	3.4	3.5	3.6	3.7	3.8	3.9
5	-	8.0	6.5	5.5	3.6	5.5	3.0	3.0	5.5
10	1.6	9.0	10.0	6.0	4.5	5.6	3.5	4.5	7.0
15	1.4	-	-	6.5	-	7.0	4.0	4.7	8.5
20	1.8	-	-	6.5	3.7	5.0	6.0	5.0	9.0
30	2.6	8.5	18.5	6.5	4.0	5.6	-	5.3	11.0
40	-	-	-	7.7	4.0	5.5	6.7	5.0	-
50	-	-	-	-	-	-	8.0	5.5	-
60	3.3	9.5	39.0	7.5	4.0	4.7	2.0	5.5	5.5
80	3.3	-	-	4.7	4.6	-	2.3	-	6.0
100	5.7	-	-	5.0	4.3	-	1.5	2.0	4.5
120	4.9	-	-	4.0	4.5	-	2.0	2.0	4.5
150	-	-	-	5.5	3.0	-	3.0	-	3.0
180	2.8	4.0	5.0	-	2.0	-	-	-	-

Notes :

\* Sampling time refers to time after the passage of spray aircraft overhead of the nymphal band from which samples were taken.

\* Vertical lines join adjacent sample means which are not significantly different from each other ( $P>0.1$ ).

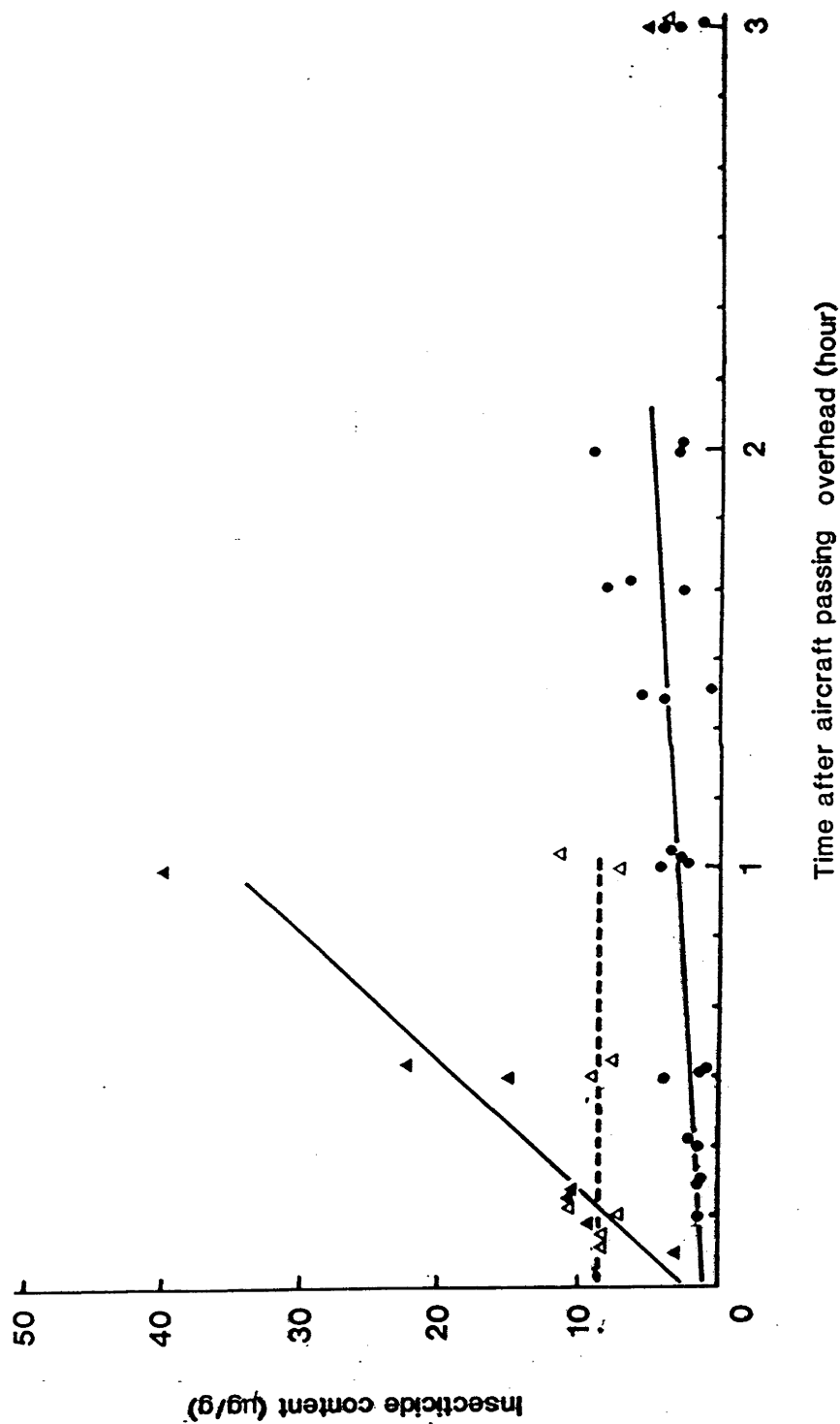


Figure 17 - Variation in fenitrothion content in aerially sprayed nymphs of *C. terminifera* with time. Examples shown are results for trials 3.1 (●), 3.2 (▲) and 3.3 (▲). 3.3 with high percentage of grass cover, 3.1 moderate, 3.2 low.

droplet impingement on the nymphs in these cases.

In trial 3.2, where the ground was almost bare, the sampling cards on the ground received an average of  $0.5 \times 10^5 \mu\text{m}^3/\text{cm}^2$  of insecticide, equivalent to approximately 70 g/ha of fenitrothion. This amount was about one-third of the actual application rate, similar to the findings by Nguyen and Symmons (1984) in monitoring the fate of ULV sprays over a sparse field of young wheat crop. The nymphs spent much time marching over the contaminated ground without accumulating insecticide, so it could be concluded that acquisition from deposit on the soil was negligible.

In the remaining trials, there was a trend for the dose to increase after application. This indicated that indirect (residual) acquisition occurred in addition to direct dosing, most likely by the nymphs coming into contact with residues on the vegetation, and probably by feeding on the contaminated grass as well. The very high level of fenitrothion (39  $\mu\text{g/g}$ ) acquired by nymphs one hour after spraying in trial 3.3 is probably a reflection of an unusually high frequency of contact that may occur between sprayed nymphs and spray residues in target areas covered by dense grassy vegetation. poison took effect.

Although there were no obvious physical or biological reasons for the increase in dose in the first hour or so to be linear, linear regression analysis gave reasonable fit to the data ( $r^2 > 0.7$ ). Estimates of the doses acquired, directly and residually, and the rates of residual acquisition are tabulated in Table 3. Also shown

TABLE 3 - ESTIMATED AMOUNTS OF INSECTICIDE ACQUIRED AND OBSERVED HOPPER MORTALITIES  
FOR INDEX OF GRASS COVER SEE TABLE 1

Trial	Direct dose ( $\mu\text{g/g}$ )	Residual dose ( $\mu\text{g/g}$ )	Rate of residual acquisition ( $\mu\text{g/g/min}$ )	Total dose ( $\mu\text{g/g}$ )	% reduction in hopper numbers
3.1	1.1	4.3	0.04	5.4	40 - 60
3.2	8.1	-	-	8.1	> 95
3.3	3.2	34.8	0.58	38.0	> 95
3.4	5.7	2.1	0.04	7.8	> 95
3.5	3.8	-	-	3.8	80 - 95
3.6	5.0	-	-	5.0	60 - 80
3.7	2.7	5.0	0.10	7.7	90 - 95
3.8	3.9	1.9	0.03	5.8	60 - 80
3.9	4.8	6.3	0.21	11.1	90 - 95



are corresponding observations of the effect on locust numbers in the bands selected for monitoring.

After about two hours, a decline in fenitrothion content was noted in all trials (Table 2). This was presumably due to the increasing bias in later samples towards the more lightly dosed nymphs. Many hoppers were already dead or moribund within an hour of spraying. Consequently, samples collected by sweep-nets then would have caught only the less affected nymphs which were still hopping. Such samples would therefore be biased sub-samples of the population, and would show lower doses. Excretion and metabolism of internally absorbed insecticide (Courshee 1968; MacCuaig 1968) also might have caused some reduction in the dose in the remaining hoppers.

### 3.3.2. Factors affecting insecticide acquisition

The density of the vegetation cover in the treated areas and the amount of chemical deposited on the vegetation appeared to be the two main factors influencing both the manner of acquisition as well as the insecticide dose received by the nymphs.

Pasture vegetation shielded the hoppers from falling spray droplets, so its density would determine whether direct or indirect acquisition was the main route of spray entry. In sparsely vegetated areas, such as in trials 3.2, 3.5 and 3.6 where the hoppers were more or less exposed, acquisition was mainly by direct droplet impingement. In denser vegetation, indirect acquisition became increasingly the dominant mode. Quantitatively, in areas

with the  $I_G$  index of grass larger than 6 approximately, acquisition was predominantly indirect.

The influence of vegetation cover on spray acquisition was well demonstrated by the results of the concurrent trials 3.2 and 3.3 (Tables 3 and 4). Locust nymphs in the same band, treated at the same time, acquired insecticide in different manners depending on whether they were on bare open ground or in tall grass. The nymphs hidden in the grass collected about half the direct dose of those in the open. The smaller initial dose collected by the hoppers shielding in denser vegetation was compensated for by the acquisition at a higher rate of residual insecticide from the contaminated grass, so that they eventually acquired a higher total dose.

The rate of residual acquisition was approximately proportional to the recovery index  $I_R$  as indicated by the ratio  $R_r$  of these two parameters (Table 4). This was to be expected, since how quickly residual insecticide was picked up would depend on the amount of spray deposit available on the vegetation. The total amount of insecticide acquired by the nymphs, both directly and indirectly, appeared to increase with increasing recovery index but this could not be proved statistically.

The ratio  $R_r$  of total dose acquired and area dosage (Table 4) provided some indication of relative spray effectiveness between the trials. The ratio  $R_r$  was similar where direct acquisition was dominant, but was notably larger where residual acquisition

TABLE 4 - EFFECTS OF VEGETATION COVER AND SPRAY RECOVERY ON INSECTICIDE ACQUISITION

Trial no.	Grass cover index I <sub>G</sub>	Main mode of acquisition	Residue on grass ± s.e. (µg/g)	Recovery index I <sub>R</sub>	Ratio R <sub>I</sub>	Ratio R <sub>T</sub>	Estimated dose for 300 mL/ha (µg/g)
Very sparse vegetation cover :							
3.2	.4	direct	172	69	-	.034	10
Sparse vegetation cover :							
3.5	3	direct	39 ± 25	117	-	.021	6
3.6	3	direct	50 ± 29	150	-	.033	10
3.8	4	direct	47 ± 11	188	.016	.032	10
3.4	4.5	direct	104 ± 29	468	.009	.027	8
Dense vegetation cover :							
3.7	6	indirect	85 ± 26	510	.020	.043	13
3.1	10	indirect	18 ± 5	180	.022	.027	8
3.9	12	indirect	98 ± 14	1176	.018	.062	19
Very dense vegetation cover :							
3.3	40	indirect	91 ± 6	3640	.016	.158	47

Notes : \* Ratio R<sub>I</sub> = (Rate of indirect acquisition in µg/g/min ÷ Recovery index I<sub>R</sub>) × 100  
 \* Ratio R<sub>T</sub> = Estimated total dose acquired in µg/g ÷ Area dosage applied in mL/ha

predominated. Comparison of results of the concurrent trials 3.2 and 3.3, and 3.8 and 3.9 indicates that the same treatments of the same hopper bands were about 2 to 5 times more effective where the treated nymphs were in the denser grass. The varying  $R_T$  ratios also indicated that doses acquired were not solely dependent on the area dosage applied.

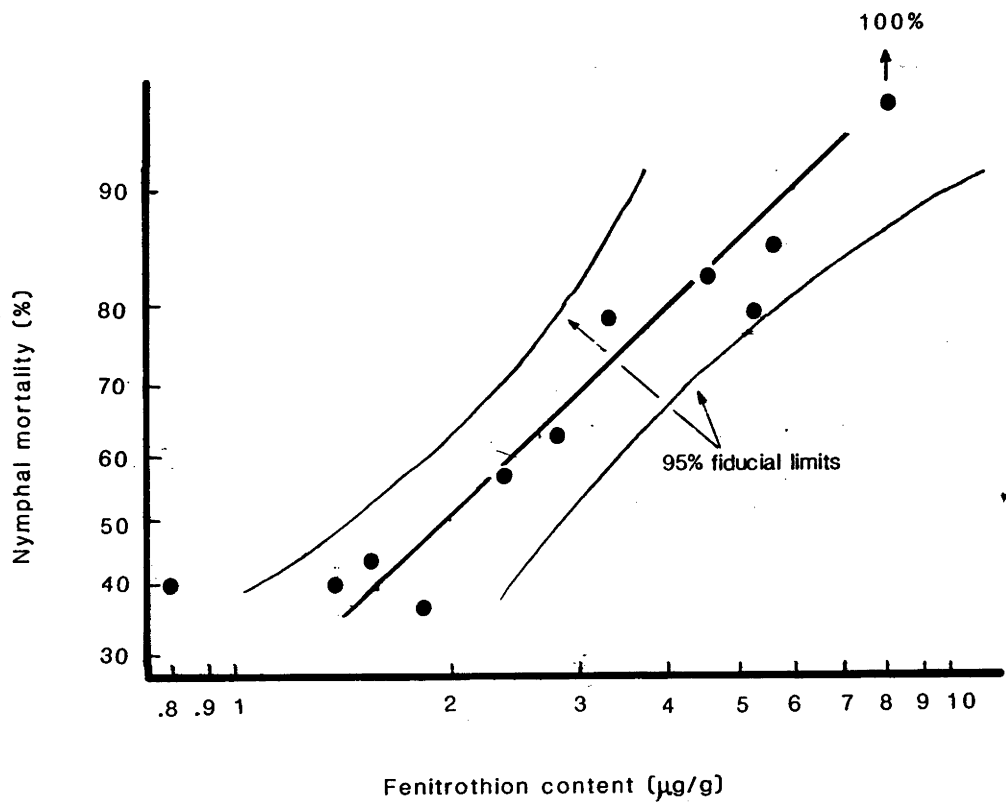
Estimates of the total dose that would have been received by the nymphs had the standard dosage of 300 mL/ha been applied, are given in Table 4. These have been derived by proportional scaling of the measured doses, assuming that all treatment conditions, except for the area dosage, remained precisely the same as in the trials.

### 3.3.3. Response to fenitrothion doses

Figure 18 shows the dose-mortality curve and the 95% fiducial limits, depicting the response of *C. terminifera* nymphs to aerially applied technical fenitrothion, after 48 hours. The data suggested an LD<sub>50</sub> of about 2.0  $\mu\text{g/g}$  (Finney 1971, according to Busvine 1971). The  $\chi^2$  value of 31.3 was significant ( $P < 0.001$ ), indicating heterogeneity. This was to be expected because of the non-ideal conditions in these field tests. There were inherent variations in the age, sex, and size of the nymphs as well as in the doses collected by individual nymphs in the same sample. In addition, the insecticide would be collected on different parts of the locust body so that the response to the same dose may vary considerably.

for the linear dose-mortality regression

The slope value of 2.7<sub>1</sub> was lower than those reported by Edge and



**Figure 18** - Relationship between the mean dose acquired (log scale) by *C. terminifera* nymphs and mortality after 48 hours (probit scale).

Casimir (1976) from bio-assays carried out on a laboratory-reared population of *C. terminifera* adults. The low slope was not unreasonable in this case, where the locust response could not be as uniform as in laboratory tests where the fenitrothion was topically applied to a precise part on the locust body (V.E.Edge, personal communication). The field test data suggested that for nymphs which were aeri ally sprayed with technical fenitrothion, the LD<sub>95</sub> would be about 8 µg/g. This was consistent with observations of nymphal mortality in the field (Table 3).

#### 3.4. Discussion

Results of these trials showed that the nymphs acquired insecticide partly by direct impingement of spray droplets and partly from residues on the vegetation. Depending on the density of vegetation cover, the direct or indirect mode of spray acquisition would be predominant.

In sparsely vegetated pasture, acquisition was mainly by droplets impinging on the locusts. Droplets which did not impinge on the nymphs and settled on the soil would probably be quickly absorbed, as found by Pfadt *et.al.* (1970) from monitoring mortalities of rangeland grasshoppers in cages. Little, if any, insecticide was collected by the nymphs from droplets deposited on the ground. These deposits, which could account for about a third of the amount of insecticide applied, were effectively lost (Himel 1974). Therefore, a sufficiently high area dosage should be applied in treating infestations in sparse grounds to ensure the nymphs acquire



direct  
a) dose equal to or more than the lethal dose of about  $8 \mu\text{g/g}$ .

The doses estimated to be collected by nymphs if they had been treated at 300 mL/ha (Table 4) indicated that this area dosage would be just adequate in these cases.

Higher doses and hence better control effectiveness were more likely to result from the treatment of infestations of nymphs in denser pastures. In such areas, residual or indirect acquisition was the more important mode of spray acquisition. The nymphs initially collected a smaller direct dose than they would in an open area, but would accumulate much more residually. The insects continued to pick up insecticide from deposits on grass after spraying was over. The rate of pick-up would be approximately proportional to the amount of insecticide deposited or recovered on grass per unit area. Thus a low residual level in a densely vegetated pasture, where the locust nymphs were more likely to come into frequent contact with the contaminated vegetation, could be as effective as a high residue in a less dense cover.

If the doses acquired by the hoppers were used as a simple measure of spray efficiency, then treatments of dense pasture would appear to be more cost effective. Estimates of doses acquired by nymphs sprayed at the standard 300 mL/ha indicated that this area dosage could be more than sufficient in certain situations and hence there was scope for reduction of area dosage.

The total dose acquired by the nymphs generally increased with the amount of insecticide recovered on grass per unit area. Insecticide

recovery on grass would therefore be a good indicator of the effectiveness of aerial control of nymphs. Increased recovery for a given dosage applied also meant increased efficiency, since a higher proportion of the emitted sprays would be available for collection by the nymphs. Spray recovery on vegetation should thus be maximised in aerial spraying of plague locust nymphs.

An additional advantage of treating hoppers in areas with some vegetation cover would be the <sup>residual</sup> protection against the locusts re-invading the treated areas. Depending on the amount of fenitrothion spray deposits, the residues may remain effective against the nymphs for up to two or more days after application (Nguyen 1983). However, certain types of vegetation such as tall bushes may not be very effective in transmitting residual insecticide since the hoppers may march underneath, without coming into contact with the contaminated foliage.

Results of these trials confirmed that the level of spray recovery and the dose acquired by the hoppers, and hence the success or otherwise of a nymphal treatment, were not solely dependent on the area dosage applied. Vegetation cover in the treated area was shown to be a significant factor influencing the effectiveness and efficiency of aerial application.

#### 4. THE DISTRIBUTION AND RECOVERY OF INSECTICIDE

##### 4.1. Introduction

As discussed previously, increased spray recovery or deposition on vegetation should be aimed for in the aerial control of nymphs. In addition, because of the random spatial distribution of nymphal bands in an infestation (Symmons 1981), spray recovery should be relatively uniform over the treated area for control to be equally effective throughout.

Generally, the distribution and recovery of low volume sprays on ground targets can be influenced by the various spraying parameters reviewed by Amsden (1964). Later reviews (e.g. Bals 1973, Johnstone 1978) highlighted the importance of parameters such as the size (or size spectrum) of the spray droplets, the transporting wind, and the height of spray release amongst others. The significance of droplet sizes has been suggested by research showing that depending on the target plants or insects, certain droplets are more likely than others to be picked up and hence are more efficient in delivering the active ingredients (Himel 1969, Bals 1974, 1975, Himel and Uk 1975, Uk 1977). The manner and efficiency with which spray droplets collect on target surfaces are also influenced by the strength of the wind (Bache and Uk 1975, Uk 1977), though wind and its associated turbulence are most influential in the transport and dispersion of the sprays, especially those comprising smaller droplets (Bache 1975, Bache and

Sayer 1975). The transport and dispersion of spray droplets are also dependent on spraying height. The higher it is and hence the farther the spray droplets have to fall to reach ground targets, the further the sprays are likely to be spread. Spraying altitude may have an additional effect through its role in influencing the initial movement and dissipation of the turbulent wake of the aircraft including wingtip vortices (Trayford and Welch 1977). Aircraft wake can entrain and elevate the spray cloud thus affecting its subsequent transport and dispersion (Lawson and Uk 1979, Parkin and Spillman 1980).

How these factors may affect the amounts and distribution of ULV spray deposits on pasture vegetation, and thus the effectiveness of aerial treatments of plague locust nymphs, have not been determined. The "preferred" droplet sizes for nymphal control are not known, and experience with the Micronair equipment and its performance in *C. terminifera* control have been too limited to allow the selection of appropriate droplet size setting. Quantitative knowledge of the effects of wind flow and spraying height on the aerial spraying of nymphs was also lacking.

Track spacing or distance between successive spray runs is an additional parameter, albeit a minor one, that requires consideration. Track spacing determines the degree of overlapping or overlaying of spray swaths in obtaining the eventual deposits and coverage (Spillman 1979). It also determines, at the upwind (and downwind) margin of the treated block, how rapidly the amount of insecticide deposit builds up to the "plateau" level. The smaller

the spacing the more rapidly this build up is, giving smaller margins of under-dosed areas, but more flying time is then needed. The selected track spacing should thus be as large as possible to economise on flying time and yet not so large as to give rise to inadequate overlapping of spray swaths, and wide low-dosed margins.

The effects of these parameters were investigated in two sets of field experiments described in this Section, to establish conditions under which aerial spraying should be conducted for effective control of *C. terminifera* nymphs. The first set of single spray run trials provided preliminary information on the distribution of droplets in a spray swath. The second set of trials were treatments which simulated the actual aerial spraying of areas infested by locust nymphs, designed to identify circumstances under which control would be effective.

#### 4.2. Methods

##### 4.2.1. Single spray run trials

The distribution of deposits with distance from the spray line was measured in these trials. The three spray parameters were varied to investigate spraying conducted under the following circumstances:

- (a) Light variable wind ( $<2$  m/s) or wind stronger than 3 m/s; wind speed was measured at 2 m above ground level.
- (b) Various spraying heights from about 2 m to about 15 m above ground.

- (c) Coarse or fine sprays, as produced by respectively the largest (50°) or smallest (25°) Micronair blade pitch setting. These two extreme settings were selected for study because droplets produced by the Micronair atomiser were not mono-dispersed but were of a range of sizes (Nguyen and Watt 1980), so there would be considerable overlap between the droplet sizes produced by adjacent settings. Of the six settings available, the largest and smallest were expected to give the least overlap between the resultant size spectra, so trial results would be likely to give the clearest indication of the effects of spray droplet size.

The aircraft made one cross-wind spray run in each trial, emitting fenitrothion at 10 L/min. Deposits on grass were sampled in a line parallel to the prevailing wind direction, at distances up to 1 km from the spray line. The distance between sampling sites varied from 20 m for the first 100 m, to 100 m at sites further than 400 m. At each sampling site, ten 25 x 3 mm strips of ULV sensitive paper were attached to the windward and upper surfaces of the vegetation, at heights of 5 to 10 cm above ground.

Approximately the same sampling line was used for all trials, to minimise the possibility that variation in vegetation cover could influence the amount of deposit collected. An additional ten papers were also laid on the ground at a number of sampling sites in some trials, to sample droplets settling on the soil in an assessment of the effects of variation in vegetation cover on spray recovery on grass. All samples collected were subsequently processed on the

Quantimet 720 Image Analysing Computer as described in Section 2.

#### 4.2.2. Area treatments

The distribution and recovery of insecticide in the treatment of a large area, such as in the aerial control of locust nymphs, were investigated in eight trials. The trials were conducted over the same pasture measuring approximately 1 x 1 km. The same area was used to minimise the effect of variation in vegetation cover. This pasture had a 40%-60% vegetative cover of couch *Agropyron repens* L., *Paspalum dilatatum* Poir. (5-10 cm), *Chloris truncata* R.Br., umbrella grass *Digitaria divaricatissima* R.Br., spear grass *Stipa* sp. and subterranean clover *Trifolium subterraneum* L. (10-30 cm).

In each treatment, fenitrothion was applied at about the standard rate of 300 mL/ha, in parallel spray runs. A track spacing of 100 m was selected for use with the insecticide emission rate of 10 L/min to achieve the required area dosage. The spray runs had been paced out and marked by flags at both ends before the trials. For trials in light winds, the track spacing was reduced to 50 m and the emission rate was halved to maintain the same area dosage. The smaller spacing was intended to ensure overlapping of the narrower swaths expected in light winds. Wind speeds were as measured with a hand-held cup anemometer at a height of 2 m; temperatures in the shade were also measured, during the trials.

Treatments were carried out for the following conditions:

- (a) in 3-5 m/s wind or in almost still (about 1 m/s) air,



- (b) with the largest or smallest Micronair blade angle of 50° or 25° to give respectively the coarsest or finest sprays,
- (c) with the aircraft flown at 3 m or 10 m height.

Deposits on the vegetation were sampled every 10 m along a line in mid-plot, between and at right angles to the seventh and ninth spray tracks downwind. Results of the earlier single spray run trials had suggested that these sampling sites would be sufficiently far from the upwind edge of the treated block to be in the deposit "plateau" area. Deposits at each site were sampled with ten small strips of sensitive paper attached to the windward and upper surfaces of the vegetation. The samples were collected 15-30 minutes post spray, for later analysis on the 720 Quantimet Image Analysing Computer.

#### 4.3. Results

##### 4.3.1. Variation in spray recovery with vegetation cover

The ratios of droplet number deposited on grass versus that collected on the soil, from the same spray cloud, provided some measure of the efficiency of capturing or recovering spray droplets by the different vegetation cover density (Table 5).

In light winds, droplets were more likely to collect on the soil than on the vegetation especially when the vegetation was sparse. As shown in Section 3, droplets collecting on the soil may be considered as lost. In denser grass, higher proportions of insecticide droplets were recovered on grass reflecting the increase

TABLE 5 - RATIOS OF DROPLET DENSITY ON GRASS TO THAT ON SOIL  
(NO./CM<sup>2</sup>) IN RELATION TO DIFFERENT DENSITIES OF  
VEGETATION COVER AND CROSS-WIND VELOCITIES.

Vegetation cover %	Wind speed (m/s)	Droplet density ratio	
		< 30 $\mu$ m	All sizes
Effect of vegetation cover / light wind			
20	0.5	0.5	0.5
30	0.5	0.9	0.9
40	1.0	1.6	1.6
Effect of vegetation cover / stronger wind			
20	2.0	1.6	2.0
40	2.0	1.8	1.9
60	3.5	3.4	3.3
80	2.0	3.7	3.0
Effect of wind speed / sparse vegetation			
20	0.5	0.5	0.5
20	2.0	1.6	2.0
20	2.5	2.6	2.5
20	3.0	3.0	2.8
20	3.5	2.5	2.5
20	4.0	3.0	3.0
20	4.5	4.5	4.5

in horizontal areas of the vegetation intercepting spray droplets which tended to settle vertically (or sediment) in light winds.

In strong winds, spray droplet capture was much less dependent on the density of grass cover and was also much higher than in light winds. In wind speeds of about 3 m/s and higher, a high proportion of droplets was recovered even if the pasture was sparse; the number of droplets on grass was about six times higher than that recovered in very light (<1 m/s) wind.

#### 4.3.2. Spray distribution in a single swath

With the coarse droplet spectrum and the aircraft flying at a height of 10 m, spraying in a light wind (<1 m/s) resulted in a relatively narrow spray swath. Most of the deposits detected were within 100 m of the spray line (Figure 19). In stronger wind (3 m/s), the peak deposit was nearly halved, but insecticide was generally more uniformly distributed up to 600 m downwind. Within this wider swath, the variation in mean droplet sizes with distance was small (Figure 20) suggesting that droplets in the spray cloud were well "mixed". In light wind, a rapid decrease in droplet sizes was observed; very large droplets <sup>with a mean diameter of</sup> 100  $\mu\text{m}$  would collect within 50 m, whereas the mean sizes at 100 m and 150 m were only 60  $\mu\text{m}$  and 35  $\mu\text{m}$  respectively (Figure 20).

The distribution patterns with the same coarse sprays, but released from 2 m are shown as dotted lines in Figure 19. In light wind, the pattern was similar to that obtained with the higher 10 m altitude,

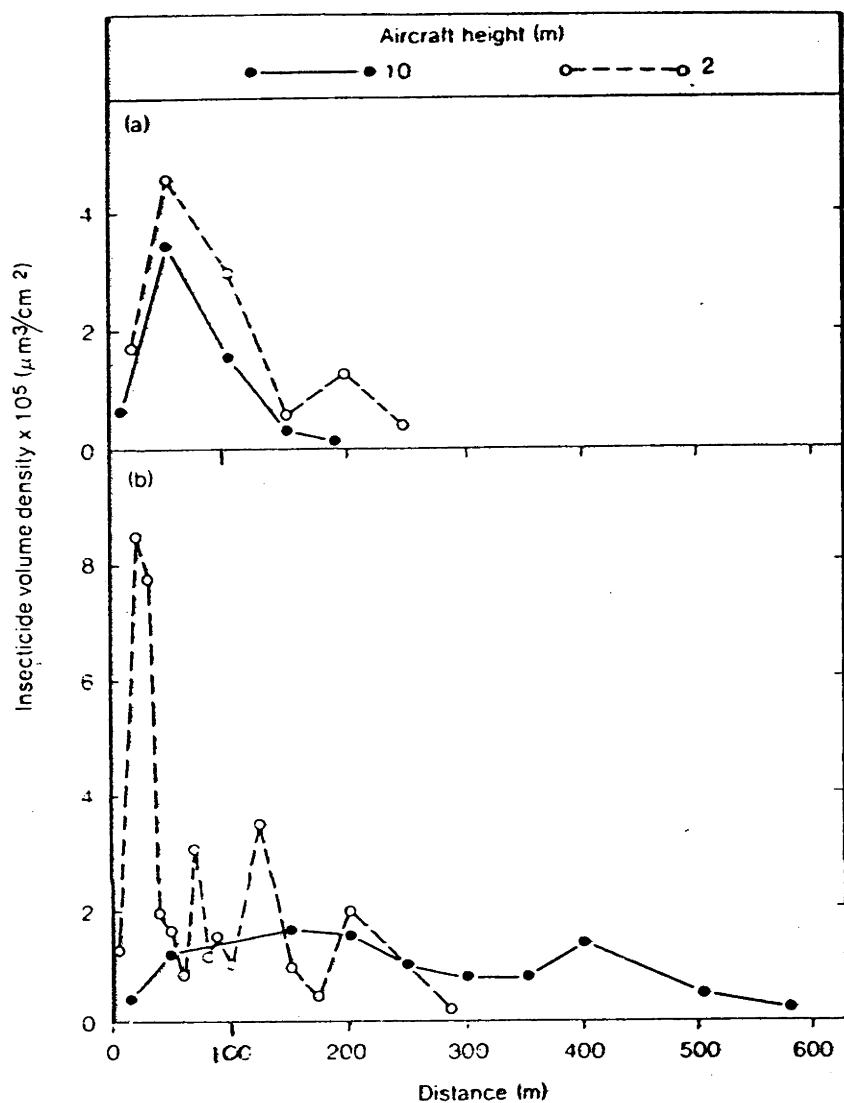


Figure 19. - Distribution of insecticide sprayed from 10 m and 2 m, using a Micronair 50° blade setting, in wind speed of (a) 0.5 m/s and (b) 3 m/s

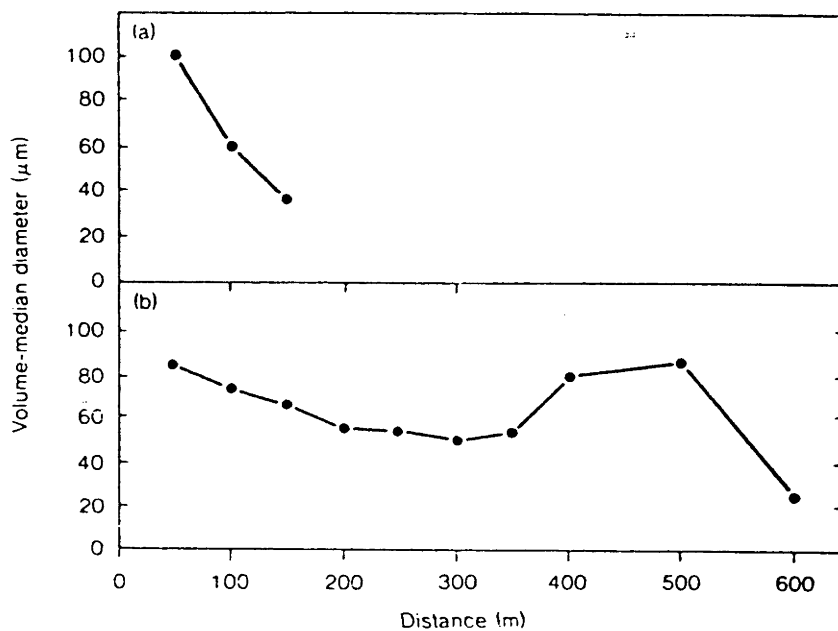


Figure 20 - Variation in mean droplet size with distance for spray swaths (shown in Figure 19) obtained with a Micronair 50° setting, 10 m spraying height and wind speeds of (a) 0.5 m/s and (b) 3 m/s.

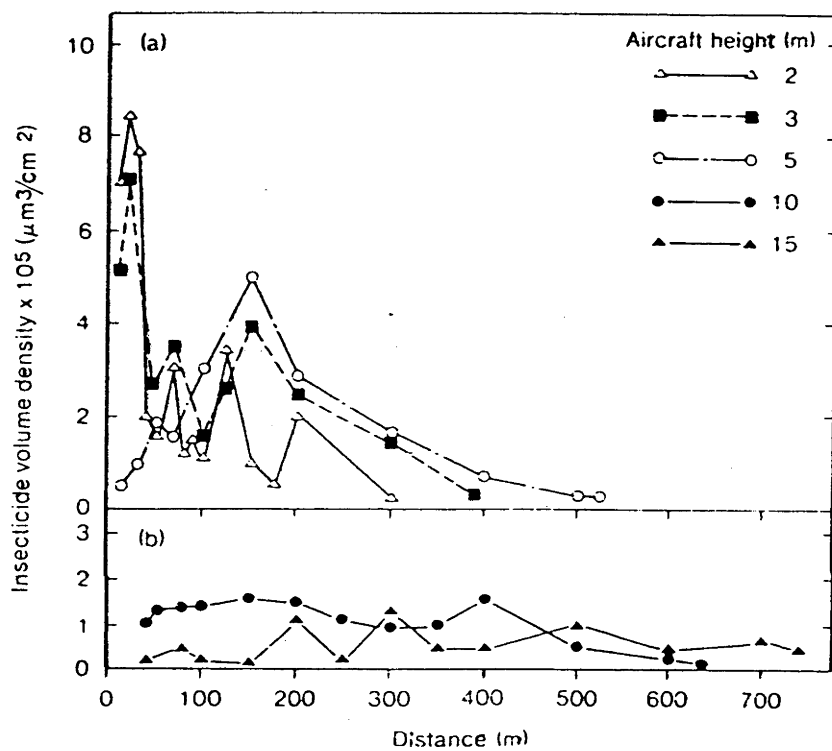


Figure 21 - Distribution of insecticide sprayed in 3-5 m/s wind, using a Micronair 50° blade setting, from heights of (a) 2 m, 3 m, 5 m and (b) 10 m, 15 m.

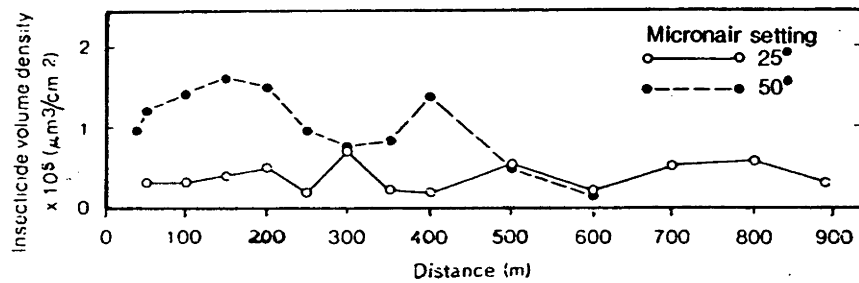


Figure 22 - Distribution of insecticide sprayed in 3 m/s wind, using a Micronair 25° blade setting. Distribution obtained with the 50° setting in similar wind speed, is also shown for comparison. Aircraft height 10m.



though slightly more insecticide was collected (Figure 19a). In strong wind, very heavy dosing occurred some 20 m downwind and distribution was highly variable with the lower altitude (Figure 19b). The effect of various spraying heights on the distribution of insecticide sprayed in a wind, is shown in Figure 21. As aircraft height was increased from 2 m to 10 m, the insecticide became more evenly distributed and the swath wider. The total amount of insecticide deposited in the swaths appeared, however, to be unaffected by the variation in aircraft spraying height.

Much wider spray swaths and uniformly low deposits were measured when the smallest Micronair blade angle of 25°, and thus the finest sprays, was selected. Spraying in a wind from 10 m gave deposits consistently less than  $1.0 \times 10^5 \mu\text{m}^3/\text{cm}^2$  which could be detected as far as 1 km downwind (Figure 22).

#### 4.3.3. Spray distribution and recovery in area treatments

The mean densities of spray droplets and volumes recovered on grass, following treatments with fenitrothion ULV at 300 mL/ha, are summarised in Table 6.

In trials 4.1 and 4.5 when the wind was strong (4 m/s), between five and six times as much insecticide was recovered as in trial 4.2 when the wind was very light. Insecticide cover was patchy in trial 4.2 despite the smaller track spacing used; deposits were much higher near the spray tracks than in between (Figure 23). Reducing aircraft height to 3 m (trials 4.3 and 4.4) did not significantly

affect the average recovery but spray coverage became markedly patchier in light wind with this lower altitude. The smaller number of droplets found in light winds (Table 6) was largely due to the recovery of fewer (39%) small droplets ( $<50\text{ }\mu\text{m}$ ) than in strong wind (51%), although the same coarse spray given by the Micronair 50° blade setting was applied (Table 7).

For trials in similar wind speeds, more droplets were deposited with the 25° blade angle than with the 50° setting (Table 6). The larger setting, however, gave nearly three times the volume recovery because of the presence of relatively larger droplets (Table 7), many of which were  $120\text{ }\mu\text{m}$  or more. In contrast, droplets produced by the 25° setting were mostly smaller than  $100\text{ }\mu\text{m}$ . The v.m.d. of droplets recovered on grass was  $70\text{ }\mu\text{m}$  with the 25° and  $120\text{ }\mu\text{m}$  with the 50° setting. Recovery in trial 4.8 was significantly lower than that in trials 4.6 and 4.7, possibly due to the increased thermal turbulence of the atmosphere associated with the higher ambient temperature during this trial (Table 6). Thermal updrafts would lift the small droplets thus preventing their deposition. Such high temperatures are commonly encountered during the locust seasons.

#### 4.4. Discussion

Results of both sets of trials clearly demonstrated the advantage of spraying in a strong wind, over spraying in light winds. In strong winds, the wind-borne spray droplets would tend to travel along a horizontal rather than a vertical trajectory. They would therefore have a higher probability of being intercepted (Bache and Uk 1975)

TABLE 6 - SPRAY RECOVERY IN AERIAL ULV APPLICATION OF FENITROTHION AT 300 mL/ha

Trial	Wind speed (m/s)	Temp. (deg C)	Micronair setting (rev/min)	Aircraft height (m)	Drop no $\pm$ s.e.	Spray recovery / cm <sup>2</sup>
4.1	4.0	22	50° (5000)	10	9.8 $\pm$ 5.1	5.5 $\pm$ 2.9 A
4.2	0.1	23	50° (5000)	10	1.8 $\pm$ 0.9	0.9 $\pm$ 0.7 B
4.3	5.0	21	50° (5000)	3	9.6 $\pm$ 4.8	5.4 $\pm$ 2.5 A
4.4	0.2	22	50° (5000)	3	1.7 $\pm$ 0.9	1.0 $\pm$ 1.5 B
4.5	4.0	18	50° (5000)	10	7.0 $\pm$ 3.5	5.4 $\pm$ 3.4 A
4.6	3.7	15	25° (12000)	10	11.0 $\pm$ 6.2	1.9 $\pm$ 1.2 C
4.7	5.7	16	25° (12000)	3	12.1 $\pm$ 5.2	1.9 $\pm$ 1.0 C
4.8	4.0	30	25° (12000)	10	8.0 $\pm$ 5.0	0.9 $\pm$ 0.6 B

Note : Spray recovery as represented by volume and number of droplets per unit area (cm<sup>2</sup>) of sensitive paper attached to grass leaves. Volumes followed by different capital letters are significantly different from each other (*t*-test, *P*<0.05)

TABLE 7 = FREQUENCY DISTRIBUTION OF SIZE OF RECOVERED DROP-  
LETS FOLLOWING ULV APPLICATION OF FENITROTHION AT

300 ML/HA.

Wind speed (m/s)	Micronair blade setting	Number of droplets counted	Percent (%) of droplets in each size class							
			1	2	3	4	5	6	7	8
3 - 5	50°	5004	20	17	14	9	12	7	7	13
0 - 2	50°	243	17	12	10	8	14	9	12	18
3 - 5	25°	6064	23	25	19	13	13	5	1	1

Note : \* Droplets smaller than 20  $\mu\text{m}$  were excluded.

\* Droplet size classes were as follows :

Class	1	2	3	4	5	6	7
Diameter ( $\mu\text{m}$ )	20-30	31-41	42-52	53-62	63-84	85-106	107-128

\* Class 8 size ranges were 129-150  $\mu\text{m}$  approx. (25° setting)  
and 129-170  $\mu\text{m}$  approx. (50° setting)

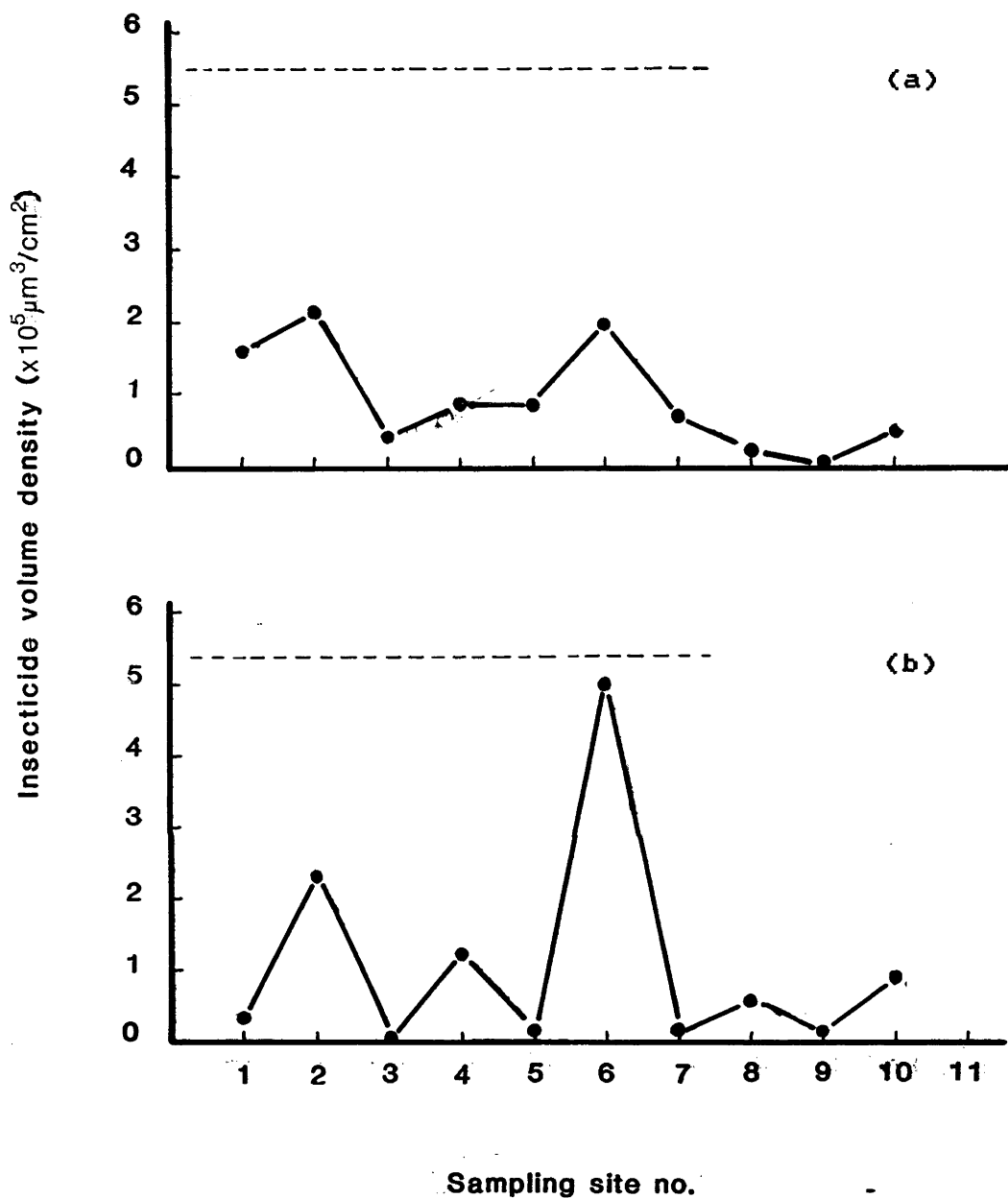


Figure 23 - Distribution of insecticide in area treatments carried out in light winds, for aircraft heights of (a) 10 m and (b) 3 m. The spray aircraft passed over sampling sites 1, 6 and 11. The dashed line indicates the average level of insecticide recovery in strong winds.

by the grass leaves than would droplets sedimenting in light winds. The wind also imparted momentum to the droplets, giving more efficient impaction on these surfaces (May and Clifford 1967).

These effects were reflected in the higher ratios of droplet number captured on grass versus that lost on the ground (Table 5) and in the levels of insecticide recovery in area treatments (Table 6). There was a marked increase in spray efficiency in strong winds; up to six times more insecticide could be recovered in winds of 3 m/s or stronger than in very light wind, when a high proportion of spray droplets was lost to the soil. The higher efficiency of droplet collection in strong wind was especially noticeable at the finer end of the droplet size spectrum. The same sprays produced by the 50° Micronair setting gave much higher number of smaller droplets in strong than in light winds (Table 7).

Droplets sedimenting in light winds tended to segregate according to sizes (Figure 20) because droplets of different sizes would fall at different rates. Larger ones, being heavier, settled out of the spray cloud earlier than the smaller droplets. Since they contained a disproportionately large volume, due to the cubed relationship between diameter and volume, the section of the spray swath near to the spray line or track would be heavily dosed (Figures 19a). The far side of the swath, on the other hand, was only lightly dosed with numerous finer droplets. In large area treatments, where several swaths were applied, the segregation of droplets resulted in pronounced peaks and troughs in the distribution pattern (Figure 23). This is reflected in the higher variation in mean deposits

(Table 6).

Such variable distribution, both in droplet number and volume deposits, would not be desirable. Control would be poor in sections with low deposit levels, and could still be unsatisfactory even at the heavily dosed sections. The small number of very large drops would only overdose a few hoppers, so the treatment would be both inefficient and ineffective. A more uniform distribution of insecticide contained in deposits of even-sized droplets would be more desirable. This was achieved by spraying in strong wind.

Droplet segregation was not observed in strong wind (Figure 20b), when spray transmission from the aircraft to the targets was influenced by turbulent dispersal rather than by sedimentation (Bache 1975, Bache and Sayer 1975). As a result, distribution of deposits over the treated area was more uniform.

Spraying in strong wind gave wide spray swaths. In 3 m/s wind, significant volume of spray droplets was sampled as far as 500 m downwind (Figure 19). In the control of locust nymphs, such wide swaths could be advantageous. They suggested that the track spacing between successive spray runs could be significantly widened from the 30 m interval previously used (Casimir 1976). This would substantially reduce the aircraft time required to treat a given area. Larger infestations could then be treated with fewer aircraft, giving both economy and effectiveness in the overall conduct of locust control campaigns.



Spray distribution and swath width were also influenced by the height from which the sprays were released. As emission height was increased, the swath became wider and more lightly dosed (Figure 21). The traditional "on-the-deck" spraying height of 2 m caused large amounts of insecticide to be deposited near to the spray line and little at the far end, as well as a highly irregular distribution. On the other hand, spraying from 15 m dispersed spray droplets over 1 km downwind, giving low deposit levels. Too large a swath might not be desirable, since several swaths would need to overlap to build up to a required deposit level. Consequently, larger areas would exist at the upwind (and downwind) edge of the treated plot, where overlapping was inadequate.

Overall, the spraying height selected did not affect average spray recovery in the treatment of an area (Table 6), as found in trials with heights of 3 m and 10 m, although the lower height tended to give a more peaky distribution (Figure 23). The appropriate aircraft flying height would probably best be determined in the field to ensure safety of operations, taking into account obstructions such as power lines and trees. Heights of about 5-10 m appeared to give acceptable spray distribution.

The 25° Micronair blade angle gave a significantly wider swath than the larger 50° setting (Figure 22). This was to be expected since the smaller setting produced finer sprays (Table 7). The wide dispersion resulted in relatively low levels of deposits throughout the swath. Overlapping of these wide swaths in the treatment of an area, gave more uniform distribution than with the 50° setting, but

average recovery was greater with the 50° angle (Table 6). This was consistent with earlier discussion on the build up of deposits by swath overlapping. It has also been observed that while very small droplets, including those smaller than about 20  $\mu\text{m}$  which were produced in large quantity by the finer setting, were probably optimal for direct impingement on insects (Himel 1969, Himel and Uk 1975), larger droplets were required for efficient deposition on vegetation surfaces (Matthews 1977, Hadaway and Barlow 1965).

The track spacing of 100 m tested in the treatments of a large area gave acceptably uniform spray distribution. There was little advantage in using a larger track spacing. Apart from the increased likelihood of inadequate dosing at the upwind and downwind edge of the treated area, already discussed, any additional saving in cost would be small. In increasing track spacing from 30 m to 100 m, the cost of aircraft flying time had already been reduced to under 10% of the total cost (in 1979) of applying fenitrothion at 300 mL/ha. The major cost would be that of the insecticide (Symmons 1979). In addition, it was found that the electric pump equipped on a number of spray aircraft could not maintain sufficiently high pressure to achieve constant emission rate above 10 L/min, for larger spacing.

In conclusion, measurements of deposits on grass in these experiments suggested that the following conditions gave consistently high and relatively uniform deposits, and should be utilised in aerial ULV spraying of *C. terminifera* nymphs :

- (a) Wind speed of 3 m/s or more.

- (b) Relatively coarse sprays, produced by the 50° Micronair blade setting.
- (c) Aircraft height between 5 m and 10 m.
- (d) Track spacing of 100 m.

## 5. BIOLOGICAL EFFECTIVENESS OF SPRAY APPLICATIONS

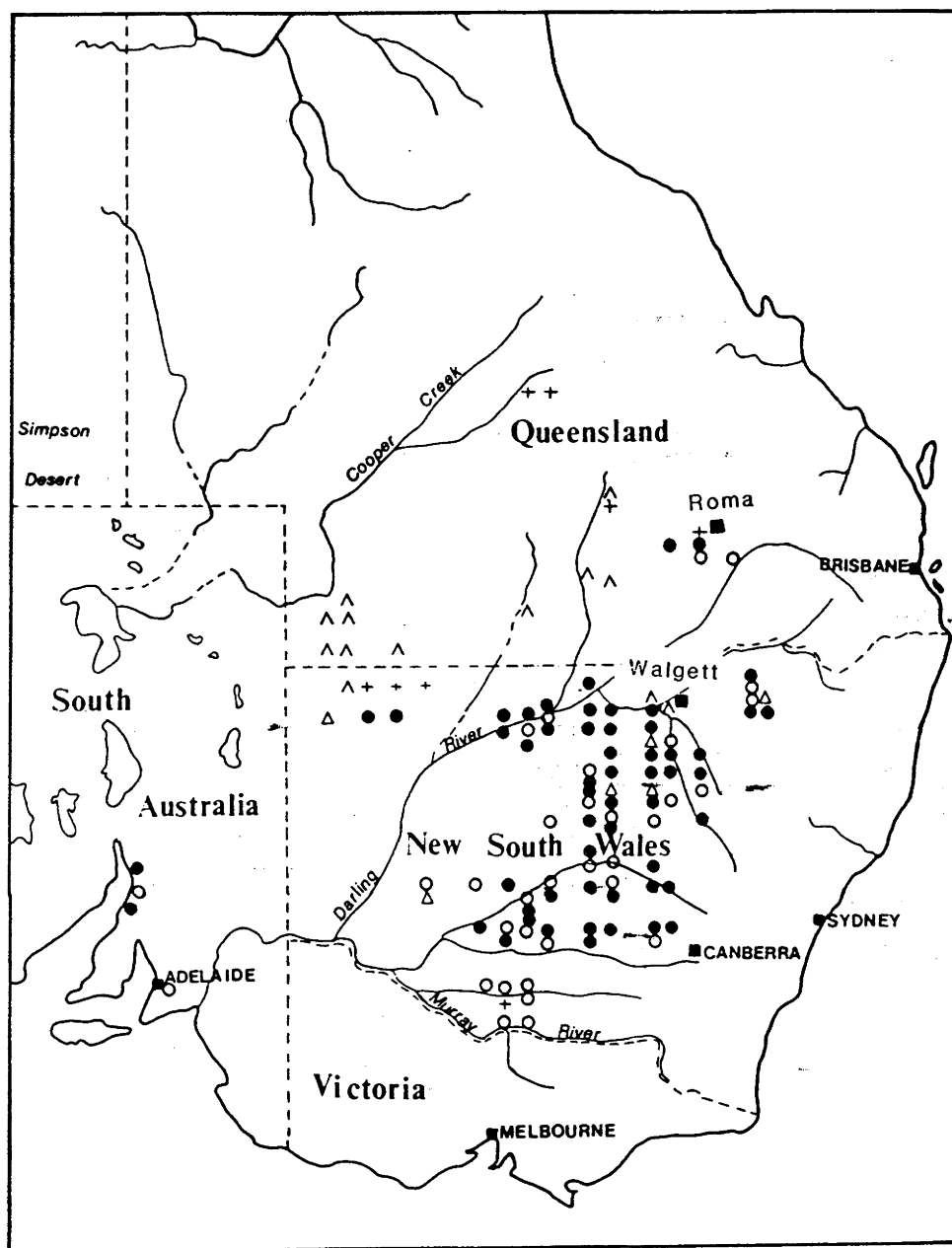
### 5.1. Introduction

The outbreak of locust infestations in the spring of 1977 provided an opportunity to confirm the biological effectiveness of the guidelines on the aerial spraying of *C. terminifera* nymphs. Three full-scale treatments were closely monitored at the commencement of an aerial campaign by the APLC seeking to control a substantial banding population in the vicinity of Walgett, NSW (Figure 24). Results are reported in this Section.

### 5.2. Methods

The treatments were carried out against infestations of *C. terminifera* nymphs of second to fourth instars near Carinda, south of Walgett. The areas treated measured approximately 4.0, 1.5, and 3.0 km<sup>2</sup>. Transects of the areas prior to spraying, in which the number of hopper bands and sub-bands (density categories according to Casimir, 1976) encountered was noted, found a heavy infestation level (Table 8).

As a check of control effectiveness in light wind, the first treatment (Trial 5.1) was conducted in 0-2 m/s wind using an 80 m track spacing, thus giving a nominal dosage of 380 mL/ha. In this trial only, sensitive paper strips were attached to the vegetation within five dense bands of nymphs in the block, ten strips to a band



■ TOWNS AND CITIES

HOPPERS	ADULTS	EGG LAYING	
+	^	v	Scattered
o	Δ	▽	Numerous
●	▲	▼	Bands/Swarms

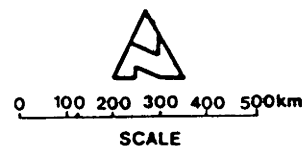


Figure 24 - Distribution of *C. terminifera* - Spring 1977.

(Source : APLC Annual Report July 1977 - June 1978)

to monitor spray deposits. These were later processed on the Quantimet Image Analyser as described in Section 2. The other treatments were carried out, according to the recommendations in Section 4, namely in stronger wind of 3-7 m/s (as measured at about 2 m height) using a 100 m spacing to give the standard 300 mL/ha area dosage. Micronair setting of 50° and aircraft spraying heights of 8-10 m were used in all treatments.

The effectiveness of the treatments was assessed based on transects of the treated areas, two days after spraying. The change in number of bands detected per kilometre of transect two days after treatment compared to that observed before was a measure of the control effectiveness. In addition, five samples of nymphs (over 30 insects per sample) were collected from the plots about 30-50 minutes after spraying and caged with unsprayed grass in plastic containers; for trials 5.1 and 5.3, five samples of treated grass were also collected at the same time for feeding unsprayed nymphs (over 30 insects per sample). The nymphs collected from the treated plots were thus exposed not only to direct sprays but also for more than 30 minutes to residues on the vegetation (Section 3), whose effect was monitored in the latter set of cages. Fifty unsprayed nymphs were caged with untreated grass as controls. Mortality counts were made daily, up to two days after treatments.

### 5.3. Results

In agreement with earlier findings (Table 6), spray recovery in trial 5.1, which was carried out in light wind, was low and



TABLE 8 - NUMBER OF HOPPER BANDS AND SUB-BANDS ENCOUNTERED ON LINE TRANSECTS  
OF TRIAL BLOCKS BEFORE, AND TWO DAYS AFTER, TREATMENTS  
WITH AERIALY-APPLIED FENITROTHION

Trial no.	Pre-treatment			Post-treatment			% reduction of bands per km of transect
	Transect length (km)	Number of bands	Number of sub-bands	Transect length (km)	Number of bands	Number of sub-bands	
5.1	9.0	11	7	7.0	10	5	-
5.2	8.0	11	20	7.6	0	1	100
5.3	5.0	15	5	8.8	1	5	96

TABLE 9 -- MEAN (AND STANDARD ERROR) PERCENT MORTALITY OF CAGED HOPPERS  
24 AND 48 HOURS AFTER TREATMENT WITH AERIALY-APPLIED  
FENITROTHION

Trial no.	Mortality of sprayed hoppers fed on unsprayed grass after		Mortality of unsprayed hoppers fed on sprayed grass after		Control mortality	
	24 hours	48 hours	24 hours	48 hours	24 h	48 h
5.1	15 + 11	37 + 25	21 + 15	37 + 15	0	5
5.2	80 + 5	93 + 7	not monitored		0	1
5.3	92 + 14	99 + 2	91 + 3	98 + 3	0	0

variable. Deposit densities varied from  $0.04 \times 10^5 \mu\text{m}^3/\text{cm}^2$  (about 0.1 droplets/ $\text{cm}^2$ ) to  $2.8 \times 10^5 \mu\text{m}^3/\text{cm}^2$  (2.8 droplets/ $\text{cm}^2$ ) giving a mean recovery of  $0.9 \times 10^5 \mu\text{m}^3/\text{cm}^2$  (1.5 droplets/ $\text{cm}^2$ ). This was similar to those measured in earlier experiments in light winds (Section 4). Hopper mortalities in the cages (Table 9) were correspondingly low and highly variable for trial 5.1. Field transects confirmed that control was unsatisfactory in this treated block, with several bands still present two days after spraying (Table 8).

In the two blocks which were treated in strong winds, the effect were evident within 30 minutes of treatment. Although the dosages of 300 mL/ha applied were lower than that applied in trial 5.1, many hoppers had died by then (Figure 25) and most of the remainder displayed acute symptoms of insecticide poisoning. A mean of 80% of those caged died within 24 hours of collection, and mortalities recorded at 48 hours in the cages were close to 100% (Table 9). Mortalities amongst unsprayed hoppers fed with treated grass were also high, indicating that the amounts of fenitrothion deposited on grass would give effective residual control. Transects of the treated area found that in trial blocks 5.2 and 5.3, hopper bands were either completely destroyed or their average densities had been reduced to less than 1 per  $\text{m}^2$  two days after treatments (Table 8); corpse densities ranging from 100 to more than 200 per  $\text{m}^2$  were counted where dense bands were previously found.

#### 5.4. Discussion

Subsequent operations in the Walgett area were carried out according to the proposed method, and good control of nymphs was reported. By the end of October 1977, locust infestations in the Walgett area had been controlled. A parallel APLC campaign in Roma, Queensland (Figure 24) also successfully eliminated dense infestations of *C. terminifera* nymphs which had posed serious threats to the local wheat crops. These results confirmed that the aerial spraying method developed in this work gave satisfactory control of nymphs at an application rate of 300 mL/ha of technical fenitrothion. The spraying method has since been widely adopted for routine control of Australian plague locust, and has proved to be consistently effective in treating populations of *C. terminifera* nymphs or of settled adult swarms.





Figure 25 - Evidence of effective aerial control of nymphs. Numerous corpses have collected in this small depression in the ground.



## 6. GENERAL DISCUSSION

### 6.1. Factors affecting aerial ULV spraying of nymphs

Work described in this thesis was primarily to establish an effective and reliable method for the aerial ULV spraying of *C. terminifera* nymphs, using Micronair spray atomisers to apply technical fenitrothion 128% w/v at 300 mL/ha. The emphasis on this practical objective has made it necessary to adopt a simplified approach and to limit the scope of study to aspects which are directly relevant to the task of defining a method for spraying nymphs.

Additional constraints have also been imposed by the high costs associated with the conduct of large scale trials of aerial spraying, and especially by the practical difficulties frequently encountered in field work which are subjected to the vagaries of the weather. Nevertheless, the study has not only resulted in the development of an effective method of spraying but has also provided some insights into the process of insecticide transfer from the spray aircraft to the nymphs on the ground. These could assist in furthering developmental work in the field of aerial application.

The acquisition of aeri ally sprayed insecticide by the hoppers was largely influenced by the vegetation cover which shielded the hoppers from the settling spray droplets. Thus, the presence or lack of vegetation, and its density determine the manner and amount



of insecticide that the nymphs eventually acquire. The doses acquired residually from the vegetation were generally higher than direct doses. This suggested that it could be more efficient to achieve nymphal control through residual acquisition rather than through direct spray acquisition, so the sprays should be targeted at vegetation in the infested areas. The amount of insecticide accumulated residually was also found to increase with increasing spray deposits (or recovery) on pasture vegetation, indicating the importance of maximising the amounts of such deposits.

The wind had a significant influence on spray droplet deposition on the vegetation. Though the study was not designed to investigate behaviour of airborne droplets, observations of spray deposit patterns provided some indications. In light wind or calm conditions, droplets would assume typically ballistic behaviour. This was reflected in the segregation of spray droplets where larger and heavier ones fell more quickly to collect closer to the spray line than finer droplets. Such behaviour was not evident in strong winds, when presumably quasi-gaseous behaviour predominated and the transport and distribution of the small droplets were largely dependent on turbulent dispersion (Cramer *et.al.* 1972, Bache 1975, Bache and Sayer 1975, Dumbauld *et.al.* 1975).

It was not clear how the difference in droplet behaviour translated into the differences observed in the amounts of insecticide recovered on the vegetation, though the study demonstrated the advantage of spraying in a stronger wind. Higher recovery and better hopper kills were obtained under such conditions than in

light winds. The results did not indicate if there is a maximum wind speed, above which control efficacy could be affected. In practice, successful treatments of *C. terminifera* nymphs have been carried out in average wind speeds of about 10 m/s. Hence, the limiting factors would seem to be considerations of safety of flight and of increased spray drift, especially in treating smaller infested area.

The study has also shown that superior results can be expected from using a coarse rather than a fine spray. The investigations only compared the relative efficacy of two extreme Micronair settings in relation to spray recovery, so that it was not certain how deposition of individual droplets was affected by their sizes. It was also not known whether the droplets produced by the recommended 50° blade setting would be of optimal sizes. There may well be conflicting requirements of droplet sizes, with smaller droplets possibly collecting better on the hoppers than on grass. However, experiences with the use of the 25° Micronair setting in hopper spraying (e.g. Wright and Nguyen 1978), have been disappointing.

Operational factors related to the conduct of spraying such as aircraft height and track spacing, could influence the patterns of spray distribution, but had minimal effects on overall spray recovery. This indicates that some flexibility in how spraying is carried out can be tolerated without impairing control effectiveness. Such flexibility is desirable since it is virtually impossible to keep spraying height and track spacing rigidly to pre-determined values.

## 6.2. Applications of results of experiments

On the basis of the above findings, a method of spraying has been formulated and recommended for the aerial ULV application of technical fenitrothion to control *C. terminifera* nymphs. The guidelines are simple and can be readily followed by field staff conducting spraying operations. The method has been in widespread use since 1977 in aerial control campaigns conducted by the APLC, and by various State locust control organisations. Successful control has generally been achieved in spraying infestations of nymphs and settled adult populations (see APLC Annual Reports). Such effectiveness has largely eliminated the need and hence the cost incurred in overdosing or having to re-treat infestations due to control failure. On a number of occasions when control has been unsatisfactory, reports from the field have indicated that these could be attributed to treatments in bare or sparsely vegetated areas, when residual accumulation of insecticide would be small.

## 6.3. Some implications of study results

- \* The insecticide applied should possess some residual activity, as does fenitrothion, since direct dosing gives low margins for error.
- \* In trials described in Section 3, where less than 300 mL/ha of fenitrothion was used, the locusts could in some cases accumulate more than the lethal dose. This suggests the

potential for reduction of the area dosage of fenitrothion from the standard 300 mL/ha. As the cost of insecticide constitutes some 90% of the application cost, there is considerable scope for savings by reducing dosage. On the other hand, lower dosages would give smaller margins for error. Preliminary tests with dosages as low as 150 mL/ha gave inconclusive results (Nguyen 1983).

- \* The recommended method, despite its proven effectiveness, may not be the most optimal method of spraying plague locust nymphs. With further investigations to better understand the behaviour of droplets in the air and in the vicinity of the vegetation surfaces, it is possible that more detailed specifications can be made to assure even better control. It is likely, then, that field personnel will require better instruments and training to be able to identify and take advantage of conditions such as atmospheric stability and turbulence intensities. Also, knowledge of optimal droplet sizes for aerial spraying of nymphs can be improved in future and appropriate spray equipment be designed for their production to obtain better results.

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